D E C L A R A T I O N

In the matter of U.S. Patent Application Ser. No. 10/049,830 in the name of Kenji TSUKADA, et al.

I, Kumi HIRANO, of Kyowa Patent and Law Office, 2-3, Marunouchi 3-Chome, Chiyoda-Ku, Tokyo-To, Japan, declare and say:

that I am thoroughly conversant with both the Japanese and English languages; and,

that the attached document represents a true English translation of Japanese Patent Application No. 2000-207193 filed on July 7, 2000.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Dated: September 19, 2003

Kumi Hirano

Kumi HIRANO

Name of Document: Patent Application

Reference Number: J0078143

Application Date: July 7, 2000

To: The Commissioner of The Patent Office

International Patent Classification: B41J 2/175

Inventor:

Address: c/o Seiko Epson Corporation,
3-5, Owa 3-Chome, Suwa-Shi, Nagano-Ken

Name: Kenji TSUKADA

Inventor:

Address: c/o Seiko Epson Corporation,
3-5, Owa 3-Chome, Suwa-Shi, Nagano-Ken

Name: Munehide KANAYA

Applicant:

Identification Number: 000002369
Name: SEIKO EPSON CORPORATION
President: Hideaki YASKAWA

Agent:

Identification Number: 100093388
Patent Attorney
Name: Kisaburo SUZUKI
Tel : 0266-52-3139

Agent:

Identification Number: 100095728
Patent Attorney
Name: Masataka KAMIYANAGI

Agent:

Identification Number: 100107261
Patent Attorney
Name: Osamu SUZAWA

Indication of the Fee

Deposit Account Number: 013044
Fee: 21,000 (yen)

List of Documents filed:

Specification	1
Drawing	1
Abstract	1
Number of General Power of Attorney	9711684

Proofreading : needed

(Translation)

SPECIFICATION 2000-207193

1. TITLE OF THE INVENTION

LIQUID CONTAINER, INK JET RECORDING APPARATUS, APPARATUS AND METHOD FOR CONTROLLING THE SAME, APPARATUS AND METHOD FOR DETECTING LIQUID CONSUMPTION STATE

2. CLAIMS:

1. A method of controlling an ink jet recording apparatus on which a liquid container is able to be detachably mounted, said liquid container having a container body containing a liquid supplied to a recording head for discharging an ink droplet from a nozzle opening and a piezoelectric device for detecting said liquid within said container body, comprising the steps of:

detecting a characteristic value of said piezoelectric device with a detection section provided inside or outside said ink jet recording apparatus;

judging whether or not said characteristic value satisfies a predetermined condition with a judging section provided inside or outside said ink jet recording apparatus; and

controlling said ink jet recording apparatus so that said ink jet recording apparatus is set in an operable state or in a non-operable state based on a result of said judging step.

2. The method of controlling an ink jet recording apparatus according to claim 1, further comprising a step of said liquid container being mounted on said ink jet recording apparatus before said detection step, which is executed at least at the time when said liquid container is mounted on said ink jet recording apparatus.

3. The method of controlling an ink jet recording apparatus according to claim 1, further comprising a step of measuring a consumption volume of said liquid within said liquid container until at least a predetermined volume with a measuring section provided inside or outside said ink jet recording apparatus.

4. The method of controlling an ink jet recording apparatus according to claim 1, further comprising a step of, in a case when said ink recording apparatus is in said non-operable state, selecting either to maintain said non-operable state of said ink jet recording apparatus or to change said non-operable state of said ink jet recording apparatus to said operable state.

5. The method of controlling an ink jet recording apparatus according to claim 1, wherein said characteristic value is an element characteristic value of a piezoelectric element of said piezoelectric device.

6. The method of controlling an ink jet recording apparatus according to claim 1, wherein said characteristic value is an oscillation characteristic value of an oscillating portion of said piezoelectric device.

7. A method of detecting a liquid consumption state of a liquid container detachably mounted on an ink jet recording apparatus, said liquid container having a container body containing a liquid supplied to a recording head for discharging an ink droplet from a nozzle opening and at least two piezoelectric devices for detecting said liquid within said container body, comprising the steps of:

detecting oscillation characteristic values of said at least two piezoelectric devices attached to said liquid container with a detection section, said detection section being provided inside or outside said ink jet recording apparatus; and

judging a consumption state of said liquid within said liquid container based on a relative condition of mutual oscillation characteristic values of said at least two piezoelectric devices with a judging section, said judging section being provided inside or outside said ink jet recording apparatus.

8. The method of detecting a liquid consumption state according to claim 7, wherein said relative condition of said oscillation characteristic values is that said oscillation characteristic values of said at least two piezoelectric devices are approximately equal to each other.

9. A liquid container comprising:

a container body containing a liquid;

a liquid supply opening for supplying said liquid outside said container body; and

a piezoelectric device for detecting said liquid within said container body, said piezoelectric device being positioned nearby a liquid level of said liquid when said liquid is not consumed.

10. The liquid container according to claim 9, further comprising an additional piezoelectric device for detecting said liquid within said container body.

11. The liquid container according to claim 10, wherein said additional piezoelectric device is positioned nearby a bottom surface of said container body.

12. The liquid container according to claim 10, wherein said additional piezoelectric device is positioned nearby said piezoelectric device, an initial liquid level when said liquid within said container body is not consumed being located between said piezoelectric device and said additional piezoelectric device.

13. The liquid container according to any one of claims 9 to 12, wherein said piezoelectric device and said additional piezoelectric device have oscillating sections contacting a medium within said container body, respectively, and

wherein oscillation characteristic values of said oscillating sections are detected.

14. The liquid container according to any one of claims 9 to 13, wherein said liquid container is adapted to be mounted on an ink jet recording apparatus that performs a recording with a recording head for discharging an ink droplet, said liquid within said container body being supplied to said recording head.

15. An ink jet recording apparatus on which a liquid container is able to be detachably mounted, said liquid container having a container body containing a liquid and a piezoelectric

device for detecting said liquid within said container body, comprising:

a recording head receiving said liquid from said liquid container and discharging an ink droplet from a nozzle opening;

a judging section for judging whether or not said characteristic value satisfies a predetermined condition; and

a controlling section for controlling said ink jet recording apparatus so that said ink jet recording apparatus is set in an operable state or in a non-operable state based on a result obtained with said judging section.

16. The ink jet recording apparatus according to claim 15, further comprising a storage device capable of storing at least said characteristic value.

17. The ink jet recording apparatus according to claim 15, further comprising a measuring section for measuring a liquid consumption volume within said liquid container until at least a predetermined value.

18. An ink jet recording apparatus on which a liquid container is able to be detachably mounted, said liquid container having a container body containing a liquid and at least two piezoelectric devices for detecting said liquid within said container body, comprising:

a recording head receiving said liquid from said liquid container and discharging an ink droplet from a nozzle opening;

a detection section for detecting oscillation characteristic values of said at least two piezoelectric devices attached to said liquid container; and

a judging section for judging a consumption state of said liquid within said liquid container based on a relative condition of mutual oscillation characteristic values of said at least two piezoelectric devices.

19. The ink jet recording apparatus according to claim 18, wherein said relative condition of said oscillation characteristic values is that said oscillation characteristic values of said at least two piezoelectric devices are approximately equal to each other.

[Detailed Description of the Present Invention]

[0001]

[Field of the Invention]

The present invention relates to a liquid container having a piezoelectric device for detecting a consumption state of liquid within the liquid container, an ink jet recording apparatus for which the liquid container can be used, an apparatus and a method for controlling the same, and an apparatus and a method for detecting a liquid consumption state.

[0002]

[Prior Art]

An ink jet recording apparatus has an ink jet recording head mounted on a carriage. The inkjet recording head is provided with pressure generation means for applying pressure to pressure generation chambers and nozzle openings for discharging the pressurized ink as ink droplets from the nozzle openings. The ink jet recording apparatus is configured so that the ink jet recording apparatus is continuously printable while ink of an ink cartridge is supplied to the recording head via a pass. The ink cartridge is configured so as to be attachable to and detachable from the recording apparatus so that the ink cartridge is easily changeable by the user at the time when the ink is completely consumed.

[0003]

Conventionally, as a method of managing an ink consumption of the ink cartridge, there are a method of managing an ink consumption by performing calculations of adding up the number of ink droplets discharged from the recording head and a volume of ink absorbed due to the maintenance using a software, a method of managing a point in time at which the ink is actually consumed by mounting electrodes on the ink cartridge for detecting an ink level and the like.

[0004]

As to the method of managing an ink consumption by performing calculations of an ink consumption by means of adding up the number of discharging ink droplets and a volume of the ink using a software, there are some problems that an error is generated due to the form of printing of the user side and a large error is generated when the same

ink cartridge is mounted again. The error not to be negligible is generated between the calculated ink consumption and the actual volume of consumption due to the circumstance of use.

[0005]

The method of managing a point in time when the ink is consumed using electrodes can manage whether the ink is present or absent with a high degree of reliability since an actual volume of the ink can be detected. However, since the detection of an ink level depends on the electrical conductivity of ink, kinds of inks for use are limited, and a sealing structure of electrodes becomes complex. Moreover, since precious metal having a good conductivity and corrosion resistance is usually used as a material for the electrodes, the manufacturing cost of the ink cartridge is increased. Furthermore, since two pieces of electrodes are required to be mounted, the number of steps of manufacturing them is increased and, as a result, the manufacturing cost is increased.

[0006]

Then, a method of detecting a liquid level of the ink by detecting a change in acoustic impedance using a piezoelectric device utilizing a piezoelectric material is proposed. In the method of detecting a liquid level of the ink using a piezoelectric device, whether the ink is present or absent can be managed in a high degree of reliability, the sealing structure of the electrodes are not to be a complex structure, and the manufacturing cost of the ink cartridge is low.

[0007]

[Problems to be Solved by the Invention]

However, in the case when the piezoelectric device is defective, the piezoelectric device is not normally operated and erroneously judges whether the ink is present or absent within the ink cartridge. Therefore, if it can be judged whether or not the piezoelectric device is normally operated, it has an advantage over the above.

[0008]

Moreover, in an ink cartridge with a defect, the reduction of an ink volume is generated due to the leakage and evaporation of the ink. Therefore, it is desired to be able to detect with the piezoelectric device that the ink cartridge is not filled with the

ink of the predetermined volume due to the defect of the ink cartridge.

[0009]

Moreover, even when an ink cartridge is manufactured, if the method can confirm whether or not the ink cartridge is filled with the ink of the predetermined volume, it has an advantage over the method that is not capable of confirming it.

[0010]

Furthermore, when the ink cartridge is utilized again for recycling and the like, the ink is refilled within the ink cartridge. If the method can detect whether or not the ink of the predetermined volume is actually present or not within the ink cartridge after the ink refilling, the method has an advantage over the method that is not capable of detecting it.

[0011]

Furthermore, it is desirable to be able to detect the cases when the ink cartridge is not properly mounted and when the ink jet recording apparatus is gradient, based on a gradient of the liquid level. Thereby, the ink jet recording apparatus is prevented from performing a poor printing.

[0012]

Accordingly, an object of the present invention is to provide a method and an apparatus for controlling an ink jet recording apparatus based on the obtained result of whether or not there is a defect of a liquid detecting function with a piezoelectric device.

[0013]

Moreover, an object of the present invention is to provide a liquid container capable of confirming that the liquid of the predetermined volume presents within the liquid container during the manufacturing of the liquid container and after the manufacturing of the same.

[0014]

Furthermore, other objects of the present invention are to provide a liquid container capable of detecting that the predetermined volume of the ink is not contained in the liquid container due to defects of the liquid container and/or the piezoelectric device, and to provide a method and an apparatus for controlling an ink jet recording apparatus based on the results of a detected ink volume.

[0015]

Still further, other objects of the present invention are to provide a liquid container capable of detecting a gradient of the liquid container in the case, e.g., when the liquid container is not properly mounted, and to provide a method and an apparatus for controlling an ink jet recording apparatus based on the results of a detected ink volume.

[0016]

Furthermore, another object of the present invention is to provide a liquid container and an ink jet recording apparatus capable of easily and properly detecting an ink volume within the liquid container.

[0017]

The object of the present invention is to supply a liquid container that can solve the above-mentioned problems. The object can be achieved with the combination of characteristics mentioned in independent claims within the scope of the claims. Subordinate claims further stipulate advantageous examples of the present invention.

[0018]

[Methods of Solving the Problems]

According to the first preferred embodiment, the present invention is a method of controlling an ink jet recording apparatus on which a liquid container is able to be detachably mounted, the liquid container having a container body containing a liquid supplied to a recording head for discharging an ink droplet from a nozzle opening and a piezoelectric device for detecting the liquid within the container body, comprising the steps of: detecting a characteristic value of the piezoelectric device with a detection section provided inside or outside the ink jet recording apparatus; judging whether or not the characteristic value satisfies a predetermined condition with a judging section provided inside or outside the ink jet recording apparatus; and controlling the ink jet recording apparatus so that the ink jet recording apparatus is set in an operable state or in a non-operable state based on a result of the judging step.

[0019]

Preferably, the method further comprises a controlling step of the liquid container being mounted on the ink jet recording apparatus before the detection step, which is executed

at least at the time when the liquid container is mounted on the ink jet recording apparatus.

[0020]

The method may further comprise a step of measuring a consumption volume of the liquid within the liquid container until at least a predetermined volume with a measuring section provided inside or outside the ink jet recording apparatus.

[0021]

The method may further comprise a step of, in a case when the ink jet recording apparatus is in the non-operable state, selecting either to maintain the non-operable state of the ink jet recording apparatus or to change the non-operable state of the ink jet recording apparatus to the operable state. Preferably, the characteristic value is an element characteristic value of a piezoelectric element of the piezoelectric device or an oscillation characteristic value of an oscillating portion of the piezoelectric device.

[0022]

According to the first embodiment of the present invention, a method of detecting a liquid consumption state of an ink jet recording apparatus on which a liquid container is able to be detachably mounted, the liquid container having a container body containing a liquid supplied to a recording head for discharging an ink droplet from a nozzle opening and at least two piezoelectric devices for detecting the liquid within the container body, comprises: a detection section for detecting characteristic values of the at least two piezoelectric devices with a detection section provided inside or outside the ink jet recording apparatus; and a judging section being provided inside or outside the ink jet recording apparatus, which judges a consumption state of the liquid within the liquid container based on a relative condition of mutual oscillation characteristic values of the at least two piezoelectric devices. In the judging step, the relative condition of the characteristic values is that the characteristic values of the at least two piezoelectric devices are approximately equal to each other.

[0023]

According to the second embodiment of the present invention, a method of detecting a liquid consumption state of an ink jet recording apparatus on which a liquid container is able to be detachably mounted, the liquid container having a container body containing a

liquid supplied to a recording head for discharging an ink droplet from a nozzle opening and a piezoelectric device for detecting the liquid within the container body, comprises: a detection section for detecting at least two oscillation characteristic values of the piezoelectric devices with a detection section provided inside or outside the ink jet recording apparatus; a judging section for judging a consumption state of the liquid within the liquid container based on a relative condition of the at least two oscillation characteristic values with the judging section provided inside or outside the ink jet recording apparatus.

[0024]

According to the first embodiment of a liquid container of the present invention, the liquid container comprises a container body containing a liquid, a liquid supply opening for supplying the liquid outside the container body, and a piezoelectric device for detecting the liquid within the container body. The piezoelectric device is positioned a little above a liquid level of the liquid when the liquid is not consumed.

[0025]

According to the second embodiment of the liquid container of the present invention, the liquid container comprises a container body containing a liquid, a liquid supply opening for supplying the liquid outside the container body, and a piezoelectric device for detecting the liquid within the container body. The piezoelectric device is positioned a little below a liquid level of the liquid when the liquid is not consumed.

[0026]

The liquid container may further comprise an additional piezoelectric device for detecting the liquid within the container body. The additional piezoelectric device may be positioned nearby a bottom surface of the container body. Moreover, the additional piezoelectric device may be positioned nearby the piezoelectric device, with an initial liquid level when the liquid within the container body is not consumed being located between the piezoelectric device and the additional piezoelectric device.

[0027]

Preferably, the piezoelectric device and the additional piezoelectric device have oscillating sections contacting a medium within the container body respectively. Oscillation characteristic values of the oscillating sections are detected. Preferably, the liquid

container is adapted to be mounted on an ink jet recording apparatus that performs a recording with a recording head for discharging an ink droplet, the liquid within the container body being supplied to the recording head.

[0028]

According to the third embodiment of the liquid container of the present invention, the liquid container comprises a container body containing a liquid, a liquid supply opening for supplying the liquid outside the container body, and a piezoelectric device for detecting the liquid within the container body. The piezoelectric device has oscillating sections contacting a medium within the container body, and the oscillating sections extend toward the liquid within the container body being consumed.

[0029]

According to the first embodiment of an ink jet recording apparatus, a liquid container is able to be detachably mounted on the ink jet recording apparatus, which has a container body containing a liquid and a piezoelectric device for detecting the liquid within the container body. The ink jet recording apparatus comprises a recording head for discharging an ink droplet from a nozzle opening and a detection section for detecting a characteristic value of a piezoelectric element of the piezoelectric device.

[0030]

According to the second embodiment of an ink jet recording apparatus, a liquid container is able to be detachably mounted on the ink jet recording apparatus, which has a container body containing a liquid and a piezoelectric device for detecting the liquid within the container body. The ink jet recording apparatus comprises a recording head for discharging an ink droplet from a nozzle opening and a judging section for judging whether or not a characteristic value of a piezoelectric element of the piezoelectric device satisfies a predetermined condition.

[0031]

Preferably, the ink jet recording apparatus further comprises a storage device capable of storing at least the characteristic value.

[0032]

Preferably, the ink jet recording apparatus further comprises a measuring section

for measuring a liquid consumption volume within the liquid container until at least a predetermined volume.

[0033]

Preferably, the ink jet recording apparatus further comprises output sections indicating predetermined items at least when a characteristic value of a piezoelectric element of the piezoelectric device does not satisfy a predetermined condition. The ink jet recording apparatus may further comprise outputting terminals outputting predetermined signals at least when the characteristic value of the piezoelectric element of the piezoelectric device does not satisfy the predetermined condition.

[0034]

According to the third embodiment of the ink jet recording apparatus, a liquid container is able to be detachably mounted on the ink jet recording apparatus, which has a container body containing a liquid and at least two piezoelectric devices for detecting the liquid within the container body. The ink jet recording apparatus comprises a recording head for discharging an ink droplet from a nozzle opening, a detection section for detecting a characteristic value of a piezoelectric element of the at least two piezoelectric devices, and a judging section for judging a consumption state of the liquid within the liquid container based on a relative condition of mutual characteristic values of the at least two piezoelectric devices. The relative condition of the characteristic values may be that the characteristic values of the at least two piezoelectric devices are approximately equal to each other.

[0035]

According to the fourth embodiment of the ink jet recording apparatus, a liquid container is able to be detachably mounted on the ink jet recording apparatus, which has a container body containing a liquid and piezoelectric devices for detecting the liquid within the container body. The ink jet recording apparatus comprises a recording head for discharging an ink droplet from a nozzle opening, a detection section for detecting at least two oscillation characteristic values of a piezoelectric element of the piezoelectric devices, and a judging section for judging a consumption state of the liquid within the liquid container based on a relative condition of at least two characteristic values of the piezoelectric devices.

[0036]

The above-described summary of the present invention does not enumerate all characteristics necessary to explain about the present invention, and sub-combinations of these characteristics can also be inventions.

[0037]

[Best Mode for Carrying out the Invention]

Hereinafter, the present invention will be described through embodiments of the invention. However, the following embodiments of the invention do not limit the scope of the invention according to the claims, and all of the combinations of the characteristics described in the embodiments are not necessarily essential for solving means for the invention.

[0038]

The fundamental concept of the present invention is to detect a liquid state within a liquid container (including the presence or absence of the liquid within the liquid container, a volume of the liquid, a liquid level of the liquid, the kind of the liquid and compositions of the liquid) by utilizing an oscillation phenomenon. Such concrete methods are considered as methods of detecting a liquid state within the liquid container by utilizing an oscillation phenomenon. For example, there is a method in which an elastic wave generation means generates an elastic wave with respect to the interior of the liquid container and detects a medium within the liquid container and a change of state thereof by receiving a reflection wave reflected by the liquid level or opposed wall. Moreover, apart from this, there is a method of detecting a change in acoustic impedance from the oscillation characteristic of an oscillating object. As methods of utilizing a change in acoustic impedance, there are a method of detecting a change in acoustic impedance by making a piezoelectric device having a piezoelectric element or an oscillating section of an actuator oscillated, subsequently measuring a counter electromotive force generated by the residual oscillation remaining in the oscillating section, and detecting an amplitude of a resonance frequency or counter electromotive force waveform, and a method of measuring an impedance characteristic of the liquid or an admittance characteristic of the liquid by a measuring device of an impedance analyzer, for example, a transmission circuit and a

change in a current value and a voltage value or a change in current value and voltage value due to a frequency when an oscillation is applied to the liquid.

[0039]

It should be noted that characteristic values of an actuator as one example of a piezoelectric device described below include at least an element characteristic value and an oscillation characteristic value. An element characteristic value means a characteristic value of a material itself having a piezoelectric character included in an actuator. For example, an electric characteristic such as a voltage value or a current value, a resistance value and an electric capacity, and an optical characteristic when a constant current or a constant voltage is applied to an actuator can be listed. An oscillation characteristic value means an oscillating characteristic of the oscillating section changing based on the change in acoustic impedance due to the change of a medium contacting the oscillating section included in the actuator. For example, an oscillating frequency and an amplitude of the oscillating section can be listed. In addition, a characteristic value of the counter electromotive force generated by the oscillation of the oscillating section is included in the oscillation characteristic value.

[0040]

Fig. 1 is a sectional view of one embodiment of an ink cartridge used for mono color ink, for example, black color ink to which the present invention is applied. In the present embodiment, in Fig, 1, a not-consumed state is shown in which ink within the ink cartridge is not discharged from the recording head (similarly, also in Fig. 2 through Fig. 5 and Fig. 18). The ink cartridge in Fig. 1 is made so as to use the method of detecting a change in at least acoustic impedance by making the oscillating section of a piezoelectric device oscillated and subsequently measuring a counter electromotive force generated due to the remaining residual oscillation in the oscillating section out of the methods described above. An actuator 106 is used as a piezoelectric device.

[0041]

The ink cartridge in Fig. 1 is equipped with a container body 1 containing ink K, an ink supply opening 2 for supplying the ink K within the container body 1 to the external of the container body 1 and an actuator 106 for detecting a consumption state

of the ink K within the container body 1. The container body 1 of the ink cartridge according to the present embodiment has a supply opening forming sidewall 1010 on which the ink supply opening 2 is provided and arranged and an opposed sidewall 1015 opposing the supply opening forming sidewall 1010.

[0042]

In the ink cartridge according to the present embodiment, the actuator 106 is provided and arranged on the internal wall of the opposed sidewall 1015 out of the internal walls of the container body 1. The actuator 106 is electrically connected to a lead wire 111 penetrating the opposed sidewall 1015. Moreover, an external terminal 107 is mounted on the external wall of the opposed sidewall 1015 so that the external terminal 107 is electrically contacted to the lead wire 111. The actuator 106 is provided and arranged on the opposed sidewall 1015. However, the receiving and delivering of an electrical signal to and from the external can be performed by being electrically connected to the external terminal 107 that exists in the external of the container body 1 via the lead wire 111. Moreover, the actuator 106 is located at the lower position of the liquid level of the ink in a not-used state of an ink cartridge, and provided and arranged nearby the liquid level of the ink. Therefore, the oscillating section of the actuator 106 is positioned at the slightly lower position with respect to the liquid level of the ink.

[0043]

The actuator 106 is not protruded to the external by being provided and arranged on the internal wall of the container body 1. Therefore, the appearance of the ink cartridge is approximately the same as the outline of an ink cartridge in which the actuator 106 is not provided and arranged except that the external terminal 107 is protruded. Therefore, a large modification in a design such as the specification of a holder of an ink cartridge of an ink jet recording apparatus is not accompanied with a physical change in the outline of the ink cartridge.

[0044]

Moreover, a hole perforated on the internal wall of the container body 1, that is, the opposed sidewall 1015 in the present embodiment is large enough so that the lead wire 111 penetrates through the hole. Therefore, it is not necessary to provide a comparatively

large hole on the sidewall of the container body 1 in order that the actuator 106 is penetrated. Hence, the internal of the container body 1 is maintained in a fluid-tight manner and the leakage of the ink within the container body 1 to the external is prevented. As a result, the ink cartridge according to the present embodiment does not require a complex sealing structure. Moreover, since the complex sealing structure is not necessary, the manufacturing cost becomes lower.

[0045]

Moreover, the element characteristic value can be detected by a current and voltage applied to the actuator 106 via the external terminal 107 and the lead wire 111.

[0046]

Furthermore, in the present embodiment, the actuator 106 is located at the lower position of the liquid level of the ink in a not-used state of the ink cartridge. And since the actuator 106 is provided and arranged nearby the liquid level of the ink, when the ink cartridge is manufactured or recycled, it can be detected whether or not the predetermined volume of the ink is actually present within the ink cartridge. Furthermore, after the ink cartridge is manufactured, due to a defect of the ink cartridge, the leakage of the ink and the evaporation of the ink may reduce the volume of the ink. In such a case, since the actuator 106 can detect whether or not the predetermined volume of ink is present within the ink cartridge, the defect of the ink cartridge can also be detected.

[0047]

Moreover, in the case when an ink cartridge is left alone for a long period as it is in a not-used state, the quality such as viscosity or the like of the ink may be getting worse by the evaporation of the ink. Therefore, the actuator 106 can judge whether the quality of the ink is good or bad to some extent by detecting that the predetermined volume of ink is not present within the ink cartridge.

[0048]

Furthermore, in the case when the ink cartridge is not properly mounted and/or in the case when the ink jet recording apparatus is gradient, although the ink cartridge is in a not-used state, it can be detected that the ink cartridge is gradient by the exposure of the actuator 106 being confirmed from the liquid level of the ink. To the contrary, it may

also be detected that the ink cartridge is gradient by the non-exposure of the actuator 106 from the liquid level of the ink although the predetermined volume of ink is consumed.

[0049]

By the height of the actuator 106 being changed with respect to the liquid level of the ink, the volume of the ink to be filled within the ink cartridge can be changed, and also the reduced volume of the ink can be modified for judging a gradient of the ink cartridge or that the ink cartridge not being good. It should be noted that the actuator 106 might also be used as the only detecting means of the medium with an oscillating means provided separately.

[0050]

Fig. 2 shows another embodiment of an ink cartridge according to the present invention. In the ink cartridge according to the present embodiment, the actuator 106 is provided and arranged on the opposed sidewall 1015 similarly to the ink cartridge according to the embodiment of Fig. 1. In the ink cartridge according to the present embodiment, the actuator 106 is provided and arranged at the slightly upper position than the liquid level of the ink in the case when the ink cartridge is in a not-used state.

[0051]

Also in the present embodiment, an element characteristic value can be detected by a current and voltage applied to the actuator 106 via the external terminal 107 and the lead wire 111.

[0052]

Moreover, in the case when the ink cartridge is not properly mounted, and in the case when the ink jet recording apparatus is gradient, although the ink cartridge is in not-used state, the gradient of the ink cartridge can be detected with the ink being detected using the actuator 106.

[0053]

Fig. 3(A) shows still another embodiment of an ink cartridge according to the present invention. In an ink cartridge according to the present embodiment, a plurality of actuators 106a and 106b are provided and arranged on the opposed sidewall 1015. Moreover, the actuators 106a and 106b are provided and arranged at the slightly lower

position than the liquid level of the ink in a not-used state of the ink cartridge and nearby the boundary between a bottom surface 1a of the container body 1 and the opposed sidewall 1015 respectively.

[0054]

Therefore, a similar effect of the actuator 106 in the embodiment of Fig. 1 can be obtained. On the other hand, at the stage of the ink end where the ink is consumed, the actuator 106b is provided so that the medium contacting the actuator 106b is changed from the ink to the gas. Therefore, the actuator 106b can detect the ink end.

[0055]

Therefore, all of the judgments of whether or not the actuators 106a and 106b have defects, the detection of whether or not the predetermined volume of the ink is present within the ink cartridge, and the detection of the ink end can be carried out with two actuators of the actuators 106a and 106b being provided and arranged as the embodiment of Fig. 3(A).

[0056]

Moreover, the consumed volume of the ink within the ink cartridge can also be detected based on the relative condition of mutual characteristic values of the actuators 106a and 106b. More specifically, a semiconductor storage means 7 stores an oscillating characteristic value of the actuator 106a detected when the predetermined volume of the ink within the ink cartridge was consumed and the ink was absent on the periphery of the actuator 106a. When the value of an oscillating characteristic value that the actuator 106b detects is approximately equal to the value of the oscillating characteristic value of the actuator 106a detected when the ink was absent on the periphery of the actuator 106a, it can be judged that the liquid level of the ink passed through the actuator 106b. Since the actuator 106b is provided and arranged nearby the liquid level of the ink at the time of the ink end of the container body 1, when it was judged that the ink passed through the liquid level, it can be judged as the ink end. Moreover, according to the present embodiment, it is not necessary to measure oscillating characteristic values of the actuators 106a and 106b in the manufacturing processes when the ink is absent within the container body 1. Therefore, the manufacturing of the actuators 106a and 106b or the ink cartridge becomes easy and the manufacturing processes can be shortened. Furthermore, it is

preferable that the actuators 106a and 106b are manufactured in the same lot number. It is because, owing to this, the characteristics of the actuator 106a and the actuator 106b are approximately equal. The ink within the ink cartridge can be precisely detected with the actuator 106a and the actuator 106b being employed, whose characteristics are approximately equal.

[0057]

Fig. 3(B) shows another embodiment of an ink cartridge according to the present invention. In the ink cartridge according to Fig. 3(B), the actuator 106b of the ink cartridge according to the embodiment of Fig. 3(A) is positioned nearby the actuator 106a. The positions of the actuator 106a and the actuator 106b are designed so that the liquid level of the ink is located between the actuator 106a and the actuator 106b when the ink cartridge is mounted on the ink jet recording apparatus. Owing to this, it can be judged that the ink cartridge is normally mounted on the ink jet recording apparatus. The actuator 106a detects that the ink is absent when the ink cartridge is mounted on the ink jet recording apparatus and it is judged that the ink cartridge is normally mounted when the actuator 106b detects that the ink is present. On the other hand, when the ink cartridge is mounted on the ink jet recording apparatus, in the case when both of the actuator 106a and the actuators 106b detect that the ink is present, it is judged that the ink cartridge is not normally mounted. Further, when the ink cartridge is mounted on the ink jet recording apparatus, in the case when both of the actuators 106a and 106b detect that the ink is absent, it can be judged that the predetermined volume portion of the ink within the ink cartridge is not filled or the ink cartridge, the actuator and/or a sub-tank unit 33 has a defect.

[0058]

Moreover, when the ink is refilled in the ink cartridge according to the embodiment of Fig. 3(B), the ink may be filled until the liquid level of the ink is located between the actuator 106a and the actuator 106b. It can be detected that the ink is filled without any shortage and excess within the ink cartridge by detecting the absence of the ink using the actuator 106a and detecting the presence of the ink using the actuators 106b.

[0059]

It should be noted that the actuators 106 in the embodiments from Fig. 1 to Fig. 3 are provided and arranged on the opposed sidewall 1015. However, the actuators 106 may be provided and arranged on the supply opening forming sidewall 1010. Moreover, as shown in Fig. 18, the actuator 106 may be provided and arranged on the apex wall located on the top of the container body 1. Moreover, in the case when two actuators 106 are provided and arranged so that the two are positioned at the same liquid level with respect to the liquid level of the ink, since only one of the actuators 106 detects the gas or the ink when the ink cartridge is provided and arranged in a gradient manner, it can be detected that the ink cartridge is gradient.

[0060]

Fig. 4 shows a sectional view in the transverse direction of still another embodiment of the ink cartridge according to the present invention. The container body 1 has intervening sidewalls 1020a and 1020b intervening between the supply opening forming sidewall 1010 (see Fig. 1) on which the ink supply opening 2 is provided and the opposed sidewall 1015 (see Fig. 1) opposing the supply opening forming sidewall 1010. In the present embodiment, the actuator 106 is provided and arranged on the intervening sidewall 1020a.

[0061]

In the present embodiment, the actuator 106 is provided and arranged at the slightly lower position than the liquid level of the ink in a not-used state of the ink cartridge on the internal wall of the intervening sidewall 1020a. However, the actuator 106 may be provided and arranged as in Fig. 1 through Fig. 3. Furthermore, in the preset embodiment, the actuator 106 is provided and arranged on the intervening sidewall 1020a that is one of the intervening sidewalls. However, it may be provided and arranged on the other intervening sidewall 1020b.

[0062]

Fig. 5 is a sectional view of an ink cartridge on which the single actuator 106 whose oscillating region is long is provided and arranged. The vibrating region of the actuator 106 extends from the neighboring of the liquid level of the ink before the ink is consumed to the bottom surface 1a.

[0063]

According to the present embodiment, all of the judgment of whether or not the actuator 106 has a defect, the detection of whether or not the ink of the predetermined volume presents in the ink cartridge, and the detection of the ink end can be carried out with the single actuator 106.

[0064]

Moreover, a consumption state of the liquid within the liquid container can be judged based on at least two oscillating characteristic values of the actuators 106.

[0065]

Fig. 6 is a perspective view seen from the backside showing one embodiment of an ink cartridge containing a plurality of kinds of ink. The container 8 is divided into three ink chambers 9, 10 and 11 with partition walls. In each ink chamber, ink supply openings 12, 13 and 14 are formed respectively. Actuators 15, 16 and 17 are provided and arranged on the supply opening forming sidewalls 1012, 1013 and 1014 respectively. The actuators 15, 16 and 17 may be provided and arranged on the other sidewalls contained in the container 1.

[0066]

Fig. 7 is a sectional view showing the embodiment of the major portions of an ink jet recording apparatus in which the ink cartridge shown in Fig. 1 is used. A carriage 30 capable of reciprocally moving in the traverse direction of a recording sheet is equipped with a sub-tank unit 33. A recording head 31 is provided on the lower surface of the sub-tank unit 33. Moreover, an ink supply needle 32 is provided on the side of an ink cartridge mounting surface of the sub-tank unit 33. Furthermore, in the case when at least a characteristic value of the actuator 106 does not satisfy the predetermined condition, a panel 2000 as an output section for indicating an error is provided and arranged within the ink jet recording apparatus. Or, an external output terminal 2500 connected to a host computer 3000 may be provided in the ink jet recording apparatus so as to indicate an error on the host computer 3000 of the external. It should be noted that the external terminal 107 in Fig. 7 is electrically or optically connected to the external output terminal 2500 via a cartridge holder (not shown in Fig. 7) of the ink jet recording apparatus and the like.

[0067]

When the ink supply opening 2 of the container body 1 is inserted along to the ink supply needle 32 of the sub-tank unit 33, a valve body 6 is set back against a spring 5, an ink pass is formed, and the ink within the container body 1 flows into an ink chamber 34. After the ink is filled into the ink chamber 34, the nozzle opening of the recording head 31 is subjected to the action of negative pressure, ink is discharged from the recording head 31 and the recording operation is carried out.

[0068]

It should be noted that, in the embodiments of Fig. 1 through Fig. 5 and Fig. 18, when the ink cartridge is mounted on the ink jet recording apparatus and the ink is filled into the ink chamber 34, it is preferable that the position of the actuator 106 and the volume of the ink chamber 34 are designed so that the liquid level of the ink is positioned at the position shown in Fig. 1 through Fig. 5 and Fig. 18. Therefore, the liquid levels of the ink shown in Fig. 1 through Fig. 5 and Fig. 18 are not always the level of the liquid level during the manufacturing of the ink cartridge.

[0069]

When the ink is consumed in the recording head 31 with the recording operation, the film valve 36 is opened since the pressure of the downstream side of a film valve 36 is lowered. Thus, the ink in the ink chamber 34 flows into the recording head 31 via an ink supply pass 35. The ink in the container body 1 flows into the sub-tank unit 33 via the ink supply needle 32 accompanied with the inflow of the ink to the recording head 31, and the printing is repeated.

[0070]

Fig. 8 is a block diagram showing the controller of an ink jet recording apparatus of the present invention. The ink jet recording apparatus of the present invention has a recording head 702 for discharging ink droplets on the recording sheet and printing, a carriage 700 for reciprocally moving the recording head 702 in the traverse direction (main scanning direction) of the recording sheet and an ink cartridge 180 for supplying the ink to the recording head 702. The carriage 700 is connected to a carriage drive motor 716. The carriage 700 and the recording head 702 reciprocally move in the traverse direction

of the recording sheet by the carriage drive motor 716 being driven. The carriage motor control means 722 controls the carriage drive motor 716.

[0071]

The actuator 106 mounted on the ink cartridge 180 is controlled by a piezoelectric device control means 720. A characteristic value of the actuator 106 controlled by the piezoelectric device control means 720 is detected by a characteristic value detecting section 810. For example, with the constant voltage applied to the actuator with the piezoelectric device control means 720, a current value flown in a piezoelectric element contained in the actuator 106 is detected by the characteristic value detecting section 810. Owing to this, the characteristic value detecting section 810 can detect the resistance value of the piezoelectric element. Moreover, the characteristic value detecting section 810 may detect the electrical capacity of the piezoelectric element with the alternating current electric source being utilized.

[0072]

The characteristic value detecting section 810 may detect an oscillating characteristic of the oscillating section of the actuator 106. For example, the piezoelectric device control means 720 applies the voltage to the actuator 106, and the characteristic value detecting section 810 detects a counter electromotive force generated by the remaining residual oscillation in the oscillating section of the actuator 106. Owing to this, the characteristic value detecting section 810 can detect a resonance frequency of the residual oscillation and the amplitude of the counter electromotive force.

[0073]

A characteristic value of the actuator 106 detected in the characteristic value detecting section 810 is sent to a characteristic value judging section 820. On the other hand, the predetermined conditions that the characteristic value should satisfy have been previously stored in the storage section 850. The predetermined conditions may be set according to the characteristic values. For example, in the case when the characteristic value is a resistance value of a piezoelectric element, the specification that the resistance value of the piezoelectric element should satisfy is defined as the predetermined condition. Moreover, for example, in the case when the characteristic value is judged as a resonance

frequency of the actuator 106, the specification that the resonance frequency should satisfy is defined as the predetermined condition. The storage section 850 sends the predetermined conditions to the characteristic value judging section 820 corresponding to the timing when the characteristic value detecting section 810 detects the characteristic value of the actuator 106. The characteristic value sent to the characteristic value judging section 820 is compared with the predetermined condition with a comparator contained in the characteristic value judging section 820.

[0074]

In the case when the characteristic value judging section 820 judges that the characteristic value does not satisfy the predetermined conditions, the characteristic value judging section 820 sends an error signal to an output section 840. The output section 840 outputs the display of the error corresponding to the error signal. The output section 840 is, for example, the panel 2000 and the external output terminal 2500 shown in Fig. 7. The external output terminal 2500 is connected to the host computer 3000 so that an error signal can be outputted to the external host computer 3000. An error display is a display indicating that the ink cartridge has a defect, that the ink cartridge should be changed, characteristic values, the results of the judgment in the characteristic value judging section 820 and the like. The error display may also be a means for generating light or voice. Moreover, the characteristic value judging section 820 sends a non-operable signal to a control section 750. The non-operable signal is a signal for making the ink jet recording apparatus be in a state that the ink jet recording apparatus does not carry out operations such as printing, cleaning, flashing and the like, that is, for making the ink jet recording apparatus be in a non-operable state. The ink jet recording apparatus that has received the non-operable signal does not carry out the operation or stops the operation. In the case when the ink jet recording apparatus is in a non-operable state, it may be designed so that the user can select the option for making the ink jet recording apparatus operate (not shown).

[0075]

On the other hand, in the case when the characteristic value judging section 820 judges that the characteristic value satisfies the predetermined conditions, the characteristic

value judging section 820 sends an operable signal to the control section 750. The operable signal is a signal for making a state that the ink jet recording apparatus can carry out the operations such as printing, cleaning, flashing, standby and the like, that is, for making the ink jet recording apparatus in an operable state. The ink jet recording apparatus that has received the operable signal can start or restart or is in a standby state prior to the operation. Furthermore, the display notifying that the output section 840 satisfies the predetermined conditions, the ink jet recording apparatus is in an operable state and the like may also be outputted.

[0076]

The timing when the characteristic value detecting section 810 detects the characteristic value of the actuator 106 may be even at the time when the ink cartridge is mounted on the ink jet recording apparatus. Moreover, it may be even at the time when the ink consumption volume measuring section 830 measures the predetermined volume portion of the ink within the ink cartridge is consumed.

[0077]

The timing when the ink consumption volume measuring section 830 measures that the predetermined volume of the ink within the ink cartridge is consumed will be described in more detail below. The ink consumption volume measurement section 830 calculates an ink consumption within the ink cartridge with an added-up volume of ink droplets discharged from the recording head and the ink volume actually used at the time of cleaning and flashing. Information of a consumed volume of the ink mathematically calculated, which has been measured in the ink consumption volume measurement section 830, is sent to the characteristic value judging section 820. On the other hand, the predetermined conditions that the consumed volume mathematically calculated should satisfy has been previously stored in the storage section 850. The predetermined conditions may be set corresponding to the volume of ink droplets discharged from the recording head, the frequency of the cleanings and flashings, the position where the actuator 106 is provided and arranged and the like. The storage section 850 sends the predetermined conditions previously stored in the characteristic value judging section 820. The characteristic value judging section 820 emits a signal to the control section 750 when a

consumed volume of the ink mathematically calculated achieves the predetermined volume in the ink consumption volume measuring section 830. The piezoelectric device control means 720 of the control section 750 apply a voltage or the like to the actuator 106 corresponding to a signal from the characteristic value judging section 820. Owing to this, the characteristic value detecting section 810 detects the characteristic value of the actuator 106.

[0078]

It should be noted that, as for the volume of the ink droplets and the volume of the ink actually used at the time of cleanings and flashings that have been previously judged in the ink consumption volume measuring section 830, errors compared with the actually discharging volume of the ink generated due to the use circumstances may arise in many cases. Therefore, it is preferable that the predetermined condition stored in the storage section 850 is made as a value to which a little more addition or a little more reduction is performed to some extent. Moreover, in the case when the characteristic value of the actuator 106 is detected when the ink cartridge is mounted on the ink jet recording apparatus, the consumed volume of the ink as the predetermined condition stored in the storage section 850 may be set as zero.

[0079]

In the ink jet recording apparatus, a cap 712 is further mounted on the non-printing region for sealing the recording head 702. The cap 712 is connected to an absorbing pump 718 via a tube, performs the cleaning of the nozzle opening of the recording head 702 by receiving the supply of negative pressure and discharging the ink from the whole nozzle of the recording head 702. Moreover, the flashing is performed with the recording head 702 positioned at the cap 712 and the ink discharged from the whole nozzle of the recording head 702. These timings of cleaning processes, flashing processes and a timing of exchanging from the printing state to the non-printing state may be timings for detecting the characteristic value of the actuator 106.

[0080]

It should be noted that the characteristic value detecting section 810, the characteristic value judging section 820, the ink consumption volume measuring section

830, the output section 840 and the storage section 850 may be provided and arranged inside the ink jet recording apparatus, for example, provided and arranged within the control section 750, or may be provided and arranged in the device that is provided and arranged outside, for example, in the external host computer. Preferably, the characteristic value detecting section 810, the characteristic value judging section 820, the ink consumption volume measuring section 830, the output section 840 and the storage section 850, which are concerning the operation of the piezoelectric device, are provided and arranged in the ink cartridge. In consideration of the case when members concerning the operation of the piezoelectric device are out of order, it is preferable that these members are configured to be able to be exchanged at the same time of the exchange of the ink cartridge. Furthermore, the characteristic value detecting section 810, the characteristic value judging section 820, the ink consumption volume measuring section 830, the output section 840 and the storage section 850, which are concerning the operation of the piezoelectric device, may be provided and arranged on the recording head that is mounted on the ink jet recording apparatus to/from which the recording head is easily attachable and detachable.

[0081]

Fig. 9 and Fig. 10 are flowcharts showing a method of controlling the ink jet recording apparatus to which the ink cartridge according to the embodiment of Fig. 1 is mounted. It should be noted that the ink cartridge according to one of the embodiments of Fig. 2 through Fig. 6 may be used instead of the ink cartridge according to the embodiment of Fig. 1.

[0082]

Fig. 9 is a flowchart showing from the stage when the ink cartridge in Fig. 1 is mounted on the ink jet recording apparatus to the stage when the ink jet recording apparatus is in an operable state or in a non-operable state.

[0083]

An operation of an ink jet recording apparatus will be described below on the basis of the flowchart of Fig. 9 while referring to Fig. 8. An ink cartridge is mounted on the ink jet recording apparatus. When the ink cartridge is mounted, the ink jet recording

apparatus recognizes that the ink cartridge is mounted. A means for recognizing that the ink cartridge is mounted is not particularly limited. For example, the mounting of the ink cartridge may be recognized by the detection of the semiconductor storage means 7 provided and arranged on the ink cartridge using the ink jet recording apparatus. Moreover, a projection (not shown) is provided on the ink cartridge, and when the ink cartridge is mounted, the projection pushes a switch (not shown) previously provided on the ink jet recording apparatus. Owing to this, the ink jet recording apparatus may recognize that the ink cartridge is mounted with the switch electrically conducted. Or, when the ink cartridge is mounted, the user may input it to the ink jet recording apparatus by any means.

[0084]

Next, the piezoelectric device control means 720 sends an element characteristic detecting signal for detecting an element characteristic value of the actuator 106 to the actuator 106. The element characteristic detecting signal is, for example, a current or a voltage. Subsequently, in Fig. 9(A), the characteristic value detecting section 810 detects the element characteristic value of the actuator 106 and the characteristic value judging section 820 judges the element characteristic value.

[0085]

In the case when an element characteristic value of the actuator 106 does not satisfy the predetermined condition, the error 0 is displayed on the output section 840. For example, the error 0 is displayed on the panel 2000 as a display section provided on the ink jet recording apparatus, or on the external host computer 3000 connected to the external output terminal 2500 provided on the ink jet recording apparatus. Or, again, an instruction S0 sending an element characteristic detection signal to the actuator 106 may be returned to the ink jet recording apparatus. In such a case, the display of the error 0 may be set to be outputted in the case when, although the element characteristic detection signal is sent the number of the predetermined times according to the instruction S0, the element characteristic value of the actuator 106 does not satisfy the predetermined condition. Furthermore, the display of the error 0 may be set to be outputted in the case when the average value of the element characteristic values of the actuator 106 does not satisfy the predetermined condition when the element characteristic detection signal is sent the

number of the predetermined times. Furthermore, it is possible to judge based on whether or not the maximum value out of a plurality of element characteristic values is in the predetermined range, or whether or not the minimum value is in the predetermined range.

[0086]

The display of the error 0 may be a display notifying only an occurrence of an error to the user. Preferably, the display of the error 0 is a display indicating that the actuator 106 is not good, the element characteristic value, the results of the judgment in the characteristic value judging section 820 or the like. At the same time as when the error 0 is displayed, the ink jet recording apparatus is in a non-operable state. The output section 840 may display that the ink jet recording apparatus is in a non-operable state. Moreover, the storage section 850 may store that the ink jet recording apparatus is in a non-operable state. Owing to this, the past data of the ink jet recording apparatus are stored. It should be noted that a non-operable state is referred to a state in which an operation as a recording apparatus is impossible. Moreover, even if the ink jet recording apparatus according to the present embodiment is in a non-operable state, it is possible to receive a signal for moving the ink cartridge into the predetermined position in order to be capable of exchanging it into a new ink cartridge, and a signal for the selection and the like being made by the user, which will be described later.

[0087]

As defects of the element characteristic value of the actuator 106, the defect of the piezoelectric element and the defective contact of the wiring to the piezoelectric element are considered. The defect of the piezoelectric element occurs since the element characteristic itself of the piezoelectric element is defective. The defective contact of the wiring to the piezoelectric element occurs since the electric contacts of a piezoelectric layer 160, an upper portion electrode 164, a lower portion electrode 166, an upper portion electrode terminal 168, a lower electrode terminal 170 and an auxiliary electrode 172 in Fig. 11, and the electric contact of the wiring from the actuator 106 to the characteristic value detecting section 810 are broken.

[0088]

The user exchanges an ink cartridge based on the display of the error 0 while

maintaining the state in which the ink jet recording apparatus is in a non-operable state. Or, it may be set that the user can select an instruction S2 in order that the ink jet recording apparatus is made in an operable state using the already mounted ink cartridge. The ink jet recording apparatus can be in an operable state by the instruction S2. It is preferable that the past errors and the contacts of the instructions including the element characteristic values of the actuator 106 have been stored in the storage section 850.

[0089]

In the case when the element characteristic value of the actuator 106 satisfies the predetermined condition, an operation signal is sent from the piezoelectric device control means 720 to the actuator 106 (see Fig. 9(B)). The actuator 106 receives the operation signal. In the case when the actuator 106 is not defective, the actuator 106 performs the predetermined operation. On the other hand, in the case when the actuator 106 is defective, the actuator 106 does not perform the predetermined operation. The judgment of whether or not the actuator 106 performed the predetermined operation can be done with the judgment of whether or not the characteristic value detecting section 810 detects the oscillation characteristic of the actuator 106 using the characteristic value judging section 820.

[0090]

In Fig. 9(B), in the case when the actuator 106 does not perform the predetermined operation, the display of an error 1 is outputted to the output section 840. In the case when the actuator 106 does not perform the predetermined operation, the instruction S1 sending the operation signal to the actuator 106 may be returned to the ink jet recording apparatus again. In such a case, that is, in the case when although the operation signal is sent the number of the predetermined times according to the instruction S1, the actuator 106 does not perform the operation, it may be set that the display of the error 1 is outputted.

[0091]

The display of the error 1 may be a display notifying only an occurrence of an error to the user. Preferably, the display of the error 1 is a display indicating that the ink cartridge is defective, or that the actuator 106 provided and arranged in the ink cartridge is defective, the characteristic value, the results of the judgment in the characteristic value

judging section 820 or the like. It can be displayed that an ink cartridge on which the actuator 106 is not provided is mounted on the ink jet recording apparatus as a display of the error 1. In the case when the actuator 106 does not perform the predetermined operation, the ink jet recording apparatus is in a non-operable state as well as the error 1 is displayed.

[0092]

The user exchanges an ink cartridge according to the display of the error 1 while the non-operable state is left maintained as it is. Moreover, it may be set that the user can select the instruction S2 in order to make it in an operable state using the already mounted ink cartridge. The ink jet recording apparatus can be in an operable state with the instruction S2. It is preferable that the past errors and instructions have been stored in the storage section 850.

[0093]

In Fig. 9(B), in the case when the actuator 106 performs the predetermined operation, it is judged whether or not the initial oscillation characteristic value obtained from the residual oscillation detected by the actuator 106 satisfies the predetermined condition. As initial oscillation characteristic values, there are a resonance frequency, an amplitude, a wavelength, the number of waves within the predetermined time period, a time period until the predetermined number of waves pass and the like of a counter electromotive force generated by the remaining residual oscillation in the oscillating section of the actuator 106. More specifically, these are shown in Fig. 11 through Fig. 19. Moreover, as to the predetermined condition, the actual measurement value may be included in the range where a certain addition or reduction is done to the actual measurement value of the characteristic value previously measured when the actuator 106 and the ink cartridge are manufactured. It should be noted that the predetermined condition may be a condition that defines only the upper limit or the lower limit.

[0094]

In Fig. 9(C), in the case when the value of the initial oscillation characteristic value does not satisfy the predetermined condition, the display of the error 2 is outputted to the output section 840. Moreover, in the case when the initial oscillation

characteristic value does not satisfy the predetermined condition, an instruction S3 sending an operation signal to the actuator 106 may be returned to the ink jet recording apparatus again. In such a case, it can be judged based on the average value, the maximum value or the minimum value of a plurality of initial oscillation characteristic values obtained by the operation performed the number of the predetermined times using the actuator 106. In the case when the average value, the maximum value or the minimum value of a plurality of initial oscillation characteristic values is not in the predetermined range, it can be set that the display of the error 2 is outputted.

[0095]

The display of the error 2 may be a display notifying only an occurrence of an error to the user. Preferably, the display of the error 2 is a display indicating that the ink cartridge is defective, the characteristic value, the results of the judgment in the characteristic value judging section 820 or the like. As defects of the ink cartridge indicated by the display of the error 2, for example, there are the case when the liquid level of the ink does not reach the position of the actuator 106 since the predetermined volume of the ink is not filled when the ink cartridge is manufactured, the case when the ink is not present on the periphery of the actuator 106 since the ink cartridge or the ink jet recording apparatus is gradient, the case when the ink evaporates with the ink cartridge left unused for a long time and the liquid level of the ink does not reach the position of the actuator 106, the case when the ink leaks or evaporates due to the defect of the ink cartridge and the liquid level of the ink does not reach the position of the actuator 106, the case when the ink cartridge once used is mounted again on the ink jet recording apparatus and the like. In the case when the initial oscillation characteristic value does not satisfy the predetermined condition, the ink jet recording apparatus is in a non-operable state as well as the error 2 is displayed.

[0096]

The user exchanges an ink cartridge according to the display of the error 2 while the non-operable state is left maintained as it is. Moreover, it may be set that the user can select the instruction S2 in order to make it in an operable state using the already mounted ink cartridge. The ink jet recording apparatus can be in an operable state with the instruction S2. It is preferable that the past errors and instructions have been stored

in the storage section 850.

[0097]

In Fig. 9(C), in the case when the initial oscillation characteristic value satisfies the predetermined condition, the ink jet recording apparatus is in an operable state.

[0098]

In Fig. 9, the flowchart when the ink cartridge is mounted on the ink jet recording apparatus is shown. However, the flowchart of Fig. 9 may be carried out immediately before the ink jet recording apparatus starts the operation. Moreover, the flowchart of Fig. 9 may be carried out when the ink jet recording apparatus is in a non-printing state. Furthermore, the flowchart of Fig. 9 may be carried out when the cleaning, flashing and wiping of the recording head are performed. Furthermore, the flowchart of Fig. 9 may be carried out in the time period previously set.

[0099]

Fig. 10 is a flowchart from the stage where, at the time when the predetermined volume of the ink is consumed, the characteristic value of the actuator 106 is detected, to the stage where the ink jet recording apparatus is in an operable state. An operation of the ink jet recording apparatus will be described based on the flowchart of Fig. 10 while referring to Fig. 8.

[0100]

As for the flowchart of Fig. 10, in the operation of the ink jet recording apparatus, for example, the flowchart may start in every time when the page is altered, in every transfer to a non-printing state, or in every elapsed time previously set.

[0101]

The ink consumption volume measuring section 830 measures the volume of the ink discharged from the recording head by counting the number of the ink droplets discharged from the recording head and the number of times of maintenance, for example, the flashings and the cleanings, for recovering clogging of the nozzle provided in the recording head and the mechanics.

[0102]

The measurement value of the volume of the ink discharged from the recording

head is approximately consistent with the consumed volume of the ink within the ink cartridge. In the case when the measurement value of the consumed volume of the ink does not reach the predetermined reference value, the operation of the ink jet recording apparatus continues. When the measurement value of the consumed volume of the ink reaches the predetermined value, the ink jet recording apparatus sends an operation signal to the actuator 106. It should be noted that, as for the predetermined reference value, in consideration of the difference between the actual consumed volume of the ink and the measurement value of the volume of the ink discharged from the recording head 31, it is preferable that a little more addition is made to the reference or a little more reduction is made to the reference.

[0103]

The actuator 106 receives an operation signal. In the case when the actuator 106 is not defective, the actuator 106 performs the predetermined operation. On the other hand, in the case when the actuator 106 is defective, the actuator 106 does not perform the predetermined operation (see Fig. 10(A)). The judgment of whether or not the actuator 106 performed the predetermined operation can be done with the detection of whether or not the characteristic value detecting section 810 detects the oscillation characteristic of the actuator 106 with the characteristic value judging section 820.

[0104]

In Fig. 10(A), in the case when the actuator 106 does not perform the predetermined operation, the display of the error 3 is carried out on the output section 840. Moreover, in the case when the actuator 106 does not perform the predetermined operation, an instruction S4 sending the operation signal to the actuator 106 may be returned to the ink jet recording apparatus again. In such a case, although the operation signal is sent the number of the predetermined times according to the instruction S4, it is set that the display of the error 3 is outputted in the case when the actuator 106 does not perform the operation.

[0105]

The display of the error 3 may be a display notifying only an occurrence of an error to the user. Preferably, the display of the error 3 is a display indicating that the ink cartridge is defective, that the actuator 106 provided and arranged in the ink cartridge

is defective, that the ink jet recording apparatus is stopped, the characteristic value, the results of the judgment in the characteristic value judging section 820 or the like. It can be displayed that the ink cartridge in which the actuator 106 is not provided is mounted on the ink jet recording apparatus as a display of the error 3. In the case when the actuator 106 does not perform the predetermined operation, the ink jet recording apparatus is in a non-operable state as well as the error 3 is displayed.

[0106]

The user exchanges an ink cartridge according to the display of the error 3 while the ink jet recording apparatus is maintained in the non-operable state. Moreover, it may be set that the user can select an instruction S5 in order to continue the printing using the already mounted ink cartridge. The ink jet recording apparatus can be in an operable state by the instruction S5. It is preferable that the past errors and instructions have been stored in the storage section 850.

[0107]

In Fig. 10(A), in the case when the actuator 106 performs the predetermined operation, it is judged whether or not an intermediate oscillation characteristic value obtained from the residual oscillation detected by the actuator 106 satisfies the predetermined condition (Fig. 10(B)). As intermediate oscillation characteristic values, there are a resonance frequency, an amplitude, a wavelength, the number of waves within the predetermined time period, a time period until the predetermined number of waves pass, and the like of a counter electromotive force generated by the remaining residual oscillation in the oscillating section of the actuator 106. In the case when the initial oscillation characteristic value is measured, it is preferable that the intermediate oscillation characteristic value is a similar kind of the characteristic value with that of the initial oscillation characteristic value. Moreover, as to the predetermined condition that the intermediate oscillation characteristic value should satisfy, the actual measurement value of the intermediate oscillation characteristic value may be included in the range in which a certain amount of addition is made to an expected value of the intermediate oscillation characteristic value or the expected value of the intermediate oscillation characteristic value is reduced by a certain amount, or in the range in which a certain amount of

addition is made to the actual measurement value of the characteristic value previously measured or the actual measurement value of the characteristic value previously measured is reduced by a certain amount when the actuator 106 and the ink cartridge are manufactured or in the range judged by the relative relation with the other characteristic value, for example, the above-mentioned initial oscillation characteristic value. It should be noted that the predetermined condition might be a condition that defines only the upper limit or the lower limit. Moreover, the predetermined condition that the intermediate oscillation characteristic value should satisfy may be identical with the condition that the initial oscillation characteristic value should satisfy. Moreover, the initial oscillation characteristic value and the intermediate oscillation characteristic value may be one or the other of at least two oscillation characteristic values detected from the single actuator 106. Furthermore, the characteristic value that the characteristic value detecting section 810 detects and that the characteristic value judging section 820 judges may be a single kind of characteristic value, or a plurality of kinds of characteristic values.

[0108]

In Fig. 10(B), in the case when the intermediate oscillation characteristic value does not satisfy the predetermined condition, the error 4 is displayed on the output section 840. Moreover, an instruction S6 sending an operation signal to the actuator 106 may be returned to the ink jet recording apparatus again. In such a case, it can be judged based on the average value, the maximum value or the minimum value of a plurality of the intermediate oscillation characteristic values obtained by the operation performed the number of the predetermined times using the actuator 106. In the case when the average value, the maximum value or the minimum value of a plurality of the intermediate oscillation characteristic value does not satisfy the predetermined condition, it can be set that the display of the error 4 is outputted to the output section 840.

[0109]

The display of the error 4 may be a display notifying only an occurrence of an error to the user. Preferably, the display of the error 4 is a display indicating that the ink cartridge is defective, the characteristic value, the results of the judgment in the characteristic value judging section 820 or the like. As defects of the ink cartridge

indicated by the display of the error 4, for example, there are the case when the ink is present on the periphery of the actuator 106 since the ink cartridge and the ink jet recording apparatus are gradient, the case when the ink is not supplied from the ink cartridge to the recording head, the case when the ink is not discharged due to the defect of the recording head and the like. In the case when the intermediate oscillation characteristic value does not satisfy the predetermined condition, the ink jet recording apparatus is in a non-operable state as well as the error 4 is displayed.

[0110]

The user exchanges the ink cartridge according to the display of the error 4 while the ink jet recording apparatus is maintained in the non-operable state. Moreover, it may be set that the user can select the instruction S5 in order to restart the operation using the already mounted ink cartridge. The ink jet recording apparatus can be in an operable state by the instruction S5. It is preferable that the past errors and instructions have been stored in the storage section 850.

[0111]

In Fig. 10(B), in the case when the intermediate oscillation characteristic value satisfies the predetermined condition, the ink jet recording apparatus is in an operable state.

[0112]

Only one of the methods in Fig. 9 and Fig. 10 may be carried out for controlling the ink jet recording apparatus. Moreover, both of the methods in Fig. 9 and Fig. 10 may be carried out as a series for controlling the ink jet recording apparatus.

[0113]

Fig. 11 and Fig. 12 show the details and equivalent circuit of the actuator 106, which is one example of a piezoelectric device. An actuator referred to herein is employed in a method of detecting at least the change in acoustic impedance and detecting a consumption state of a liquid within the liquid container. In particular, it is employed in a method of detecting at least the change in acoustic impedance by detecting resonance frequency from the residual oscillation and detecting a consumption state of a liquid within the liquid container. Fig. 11(A) is an enlarged plan view of the actuator 106. Fig. 11(B) shows a section taken along the line B-B of the actuator 106. Fig.

11(C) shows a section taken along the line C-C of the actuator 106. Furthermore, Fig. 12(A) and Fig. 12(B) show the equivalent circuits of the actuator 106. Moreover, Fig. 12(C) and Fig. 12(D) show the actuator 106 and its peripherals and an equivalent circuit thereof when the ink is filled within the ink cartridge respectively, and Fig. 12(E) and Fig. 12(F) show the actuator 106 and its peripherals and an equivalent circuit thereof when the ink is absent within the ink cartridge respectively.

[0114]

The actuator 106 has a substrate 178 having a circular opening 161 at its approximate center, an oscillation plate 176 arranged on one of the faces (hereinafter, referred to as surface) of the substrate 178 so as to cover the opening 161, a piezoelectric layer 160 arranged on the side of the surface of the oscillation plate 176, an upper portion electrode 164 and a lower portion electrode 166 sandwiching the piezoelectric layer 160 from both sides, an upper portion electrode terminal 168 electrically coupled to the upper portion electrode 164, a lower portion electrode terminal 170 electrically coupled to the lower portion electrode 166, and a auxiliary electrode 172 provided and arranged between the upper portion electrode 164 and the upper portion electrode terminal 168 and electrically coupling both of these. The piezoelectric layer 160, the upper portion electrode 164 and the lower portion electrode 166 have a circular portion as a major portion respectively. The respective circular portions of the piezoelectric layer 160, the upper portion electrode 164 and the lower portion electrode 166 form the piezoelectric elements.

[0115]

The oscillation plate 176 is formed so as to cover the opening 161 on the surface of the substrate 178. The cavity 162 is formed with the portion facing the opening 161 of the oscillation plate 176 and the opening 161 of the surface of the substrate 178. The face of the contrary side (hereinafter, referred to as reverse face) of a piezoelectric element of the substrate 178 faces the liquid container side, and the cavity 162 is configured so as to contact a liquid. The oscillation plate 176 is mounted with respect to the substrate 178 in fluid-tight manner so that, even if a liquid enters within the cavity 162, the liquid does not leak to the surface side of the substrate 178.

[0116]

The lower portion electrode 166 is located on the surface of the oscillation plate 176, that is to say, on the face of the contrary side of the liquid container, and it is mounted so that the center of the circular portion that is the major portion of the lower portion electrode 166 and the center of the opening 161 are approximately consistent with each other. It should be noted that it is set that an area of the circular portion of the lower portion electrode 166 is smaller than that of the opening 161. On the other hand, on the surface side of the lower portion electrode 166, the piezoelectric layer 160 is formed so that the center of its circular portion and the center of the opening 161 are approximately consistent with each other. It is set that the area of the circular portion of the piezoelectric layer 160 is smaller than that of the opening 161 and larger than that of the circular portion of the lower portion electrode 166.

[0117]

On the other hand, on the surface side of the piezoelectric layer 160, the upper portion electrode 164 is formed so that the center of the circular portion that is its major portion and the center of the opening 161 are approximately consistent with each other. It is set that an area of the circular portion of the upper portion electrode 164 is smaller than those of the circular portion of the opening 161 and the piezoelectric layer 160 and larger than that of the circular portion of the lower portion electrode 166.

[0118]

Therefore, the major portion of the piezoelectric layer 160 has a structure so that its major portion is sandwiched from the front face side and the back face side with the major portion of the upper portion electrode 164 and the major portion of the lower portion electrode 166 respectively, and the piezoelectric layer 160 can be effectively deformed and driven. The circular portions that are the major portions of the piezoelectric layer 160, the upper portion electrode 164 and the lower portion electrode 166, respectively, form piezoelectric elements in the actuator 106. As described above, the piezoelectric element contacts the oscillation plate 176. Moreover, the largest area is the area of the opening 161 among the circular portion of the upper portion electrode 164, the circular portion of the piezoelectric layer 160, the circular portion of the lower

portion electrode 166 and the opening 161. Owing to this structure, the actually oscillating region out of the oscillation plate 176 is determined by the opening 161. Moreover, since the circular portion of the upper portion electrode 164, the circular portion of the piezoelectric layer 160 and the circular portion of the lower portion electrode 166 are smaller than that of the opening 161, the oscillation plate 176 is more easily oscillating. Moreover, when the circular portions of the upper portion electrode 164 and the lower portion electrode 166 electrically connected with the piezoelectric layer 160 are compared, the circular portion of the lower portion electrode 166 is smaller. Therefore, the circular portion of the lower portion terminal 166 judges the portion of the piezoelectric layer 160 where the piezoelectric effect is generated.

[0119]

The upper portion electrode terminal 168 is formed on the front face of the oscillation plate 176 so that it electrically connects the upper portion electrode 164 via the auxiliary electrode 172. On the other hand, the lower portion electrode terminal 170 is formed on the front face side of the oscillation plate 176 so that it electrically connects the lower portion electrode 166. The upper portion electrode 164 is formed on the front face side of the piezoelectric layer 160, on the way of being connected with the upper portion electrode terminal 168, it is necessary to have a step difference equivalent to the sum of the thickness of the piezoelectric layer 160 and the thickness of the lower portion electrode 166. It is difficult to form this step difference only with the upper portion electrode 164. Even if it is possible, the connection state between the upper portion electrode 164 and the upper portion electrode terminal 168 becomes fragile, and there may be a risk of being cut in the connection. Therefore, the upper portion electrode 164 and the upper portion electrode terminal 168 are connected with the auxiliary electrode 172 employed as an auxiliary member. In such a manner, it becomes a structure that the piezoelectric layer 160 as well as the upper portion electrode 164 is supported by the auxiliary electrode 172, the desired mechanical strength can be obtained, and the connection between the upper portion electrode 164 and the upper portion electrode terminal 168 is capable of being secured.

[0120]

It should be noted that the piezoelectric element and the oscillating region directly

facing the piezoelectric element out of the oscillating plate 176 are the oscillating section actually oscillating in the actuator 106. Moreover, it is preferable that members contained in the actuator 106 are integrally formed with being burnt each other. The treatment of the actuator 106 becomes easier by the integral forming of the actuator 106. Furthermore, the oscillating property is enhanced by the enhancement of the strength of the substrate 178. Specifically, with the strength of the substrate 178 being enhanced, only the oscillating section of the actuator 106 vibrates and portions except for the oscillating section do not vibrate. Moreover, the purpose for making the portions except for the oscillating section of the actuator 106 not vibrate can be achieved with the piezoelectric element of the actuator 106 made thinner and smaller and the oscillation plate 176 made thinner in contrast to the strength of the substrate 178 being enhanced.

[0121]

As a material for the piezoelectric layer 160, it is preferable to employ lead zirconate titanate (PZT), lead lanthanum zirconate titanate (PLZT) or leadless piezoelectric film in which lead is not used, and as a material for the substrate 178, it is preferable to employ zirconia or almina. Moreover, for the oscillation plate 176, it is preferable to employ the same material as the substrate 178. For the upper portion electrode 164, the lower portion electrode 166, the upper portion electrode terminal 168 and the lower portion electrode terminal 170, a material having electrical conductivity, for example, a metal such as gold, silver, copper, platinum, aluminum, nickel or the like can be used.

[0122]

The actuator 106 constituted as described above can be applied to a container for containing a liquid. For example, the actuator can be mounted on an ink cartridge and an ink tank, or a container containing a washing solvent for solving a recording head and the like.

[0123]

The actuator 106 shown in Fig. 11 and Fig. 12 is mounted in the predetermined position on the liquid container so that the cavity 162 is contacted with a liquid contained within the liquid container. In the case when the liquid is sufficiently contained within the liquid container, the interior of the cavity 162 and its outside are

filled with the liquid. On the other hand, when the liquid within the liquid container is consumed and the liquid level is lowered to the point lower than the mounting position of the actuator, a state in which either the liquid does not exist within the cavity 162 or the liquid remains only within the cavity 162 and gas exists its outside. The actuator 106 detects at least a difference in acoustic impedance caused by this change of a state. Owing to this, the actuator 106 can detect whether or not it is a state in which a liquid is sufficiently contained within the liquid container or more than a certain volume of the liquid is consumed. Furthermore, the actuator 106 is capable of detecting a kind of the liquid within the liquid container.

[0124]

Now, the principle of a liquid level detection with an actuator will be described below.

[0125]

In order to detect a change in acoustic impedance of the medium, an impedance property or admittance property of the medium is measured. In the case when an impedance property or admittance property is measured, for example, a transmission circuit can be utilized. A transmission circuit applies a certain voltage to the medium and measures the electric current supplied to the medium with the change in frequency. Or, a transmission circuit supplies a certain electric current to the medium and measures the voltage applied to the medium with the change in frequency. A change in current value or voltage value measured in the transmission circuit indicates a change in acoustic impedance. Moreover, a change in frequency fm whose current value or voltage value becomes maximum or minimum also indicates a change in acoustic impedance.

[0126]

Apart from the above-described method, an actuator can detect a change in acoustic impedance of a liquid with only a change in resonance frequency being employed. As a method of utilizing a change in acoustic impedance of a liquid, there is a method that, in the case when resonance frequency is detected with the measurement of a counter electromotive force generated by a residual oscillation remaining in an oscillating section after the oscillating section of an actuator, for example, a piezoelectric element can be utilized.

A piezoelectric element is an element for generating a counter electromotive force with residual oscillation remaining in an oscillating section of the actuator, a power of a counter electromotive force is changed with an amplitude of the oscillating section of the actuator. Therefore, the larger the amplitude of the oscillating section of the actuator is, the easier it is detected. Moreover, a cycle of the change in power of a counter electromotive force is changed by a frequency of the residual oscillation in the oscillating section of the actuator. Therefore, a frequency of the oscillating section of the actuator corresponds to a frequency of a counter electromotive force. By the way, resonance frequency is referred to a frequency in a resonance state of the oscillating section of the actuator and the medium contacting the oscillating section.

[0127]

In order to obtain resonance frequency fs, Fourier transform is performed to a waveform obtained by measuring a counter electromotive force when the oscillating section and the medium are in a state of resonance. Since an oscillation of an actuator accompanies not only a deformation in one direction but also a variety of deformations such as deflection, extension and the like, it has a variety of frequencies including the resonance frequency fs. Hence, the resonance frequency fs is judged by performing Fourier transform to a waveform of the counter electromotive force when the piezoelectric element and the medium are in a state of resonance and specifying the most predominant frequency component.

[0128]

A frequency fm denotes a frequency at the time when the admittance of the medium is maximum or the impedance of the medium is minimum. Supposing a resonance frequency is fs, frequency fm generates a subtle error with respect to resonance frequency fs by a dielectric loss or mechanical loss of the medium. However, since it is troublesome to lead resonance frequency fs from the frequency fm actually measured, in general, frequency fm is replaced by a resonance frequency and used. There, the actuator 106 can detect at least acoustic impedance by inputting an output of the actuator 106 into the transmission circuit.

[0129]

It has been proved by the experiment that there is almost no difference between

a resonance frequency specified by a method of measuring impedance property or admittance property of the medium and measuring frequency fm and a resonance frequency specified by a method of measuring resonance frequency fs by measuring a counter electromotive force generated by a residual oscillation in the oscillating section of an actuator.

[0130]

The oscillating region of the actuator 106 is a portion composed of the cavity 162 determined by the opening 161 out of the oscillation plate 176. In the case when the liquid container is sufficiently contained within the liquid container, the cavity 162 is filled with a liquid and the oscillating region contacts the liquid within the liquid container. On the other hand, in the case when the liquid container is not filled with the liquid, the oscillating region contacts the liquid remaining in the cavity within the container, or the oscillating region does not contact the liquid but contacts gas or vacuum.

[0131]

In the actuator 106 of the present invention, the cavity 162 is provided. Owing to this, it is designed so that in the oscillating region of the actuator 106, a liquid within the liquid container remains. The reasons are as follows.

[0132]

Depending on the mounting position and mounting angle to the liquid container of the actuator, the liquid is attached to the oscillating region of the actuator, although the liquid level of the liquid within the liquid container is lower than the mounting position of the actuator. In the case when the actuator detects the presence or absence of the liquid only by the presence or absence of the liquid in the oscillating region, the liquid attached to the oscillating region of the actuator hinders it from precisely detecting the presence or absence of the liquid. For example, in a state when the liquid level is lower than the mounting position of the actuator, if the liquid container is swung by reciprocating movement of the carriage and the like, the liquid is waved and the liquid droplets are attached to the oscillating region, the actuator erroneously judges that the liquid sufficiently exists within the liquid container. Therefore, to the contrary, by positively providing a cavity designed to precisely detect the presence or absence of the liquid even in the case

when the liquid remains there, if the liquid container is swung and the liquid level is waved, it is possible to prevent malfunction of the actuator. In this way, malfunction can be prevented by the employment of an actuator having a cavity.

[0133]

Moreover, as shown in Fig. 12(E), the case when the liquid is absent within the liquid container and the liquid within the liquid container remains in the cavity 162 of the actuator 106 is made as threshold. Specifically, in the case when the liquid is absent on the periphery of the cavity 162 and the liquid within the cavity is less than this threshold, the absence of the ink is determined, in the case when the liquid is present on the periphery of cavity 162 and the liquid is more than this threshold, the presence of the ink is determined. For example, in the case when the actuator 106 is mounted on the sidewall of the liquid container, the case when the liquid within the liquid container is lower than the mounting position of the actuator is determined as the case when the ink is absent, and the case when the liquid within the liquid container is higher than the mounting position of the actuator is determined as the case when the ink is present. In this way, with the threshold provided, even the case when the ink within the cavity is dried and the ink is absent is also determined as the case when the ink is absent, the case when the ink is absent within the cavity and when the ink is attached to the cavity by the swinging of the carriage and the like can be determined as the case when the ink is absent because it does not exceed the threshold.

[0134]

Now, an operation and the principle of detecting a state of the liquid within the liquid container from the resonance frequency of the medium and the oscillating section of the actuator 106 by the measurement of a counter electromotive force with reference to Fig. 11 and Fig. 12 will be described below. In the actuator 106, a voltage is applied to the upper portion electrode 164 and the lower portion electrode 166 via the upper portion electrode terminal 168 and the lower electrode terminal 170. Out of the areas of the piezoelectric layer 160, the electric field is generated in the portion sandwiched between the upper portion electrode 164 and the lower portion electrode terminal 166 respectively. The piezoelectric layer 160 is deformed by its electric field. The oscillating

region out of the oscillation plate 176 is deflected and vibrated with the piezoelectric layer 160 being deformed. After the piezoelectric layer 160 is deformed, for a while, the deflected oscillation remains in the oscillating section of the actuator 106.

[0135]

A residual oscillation is a free oscillation of the oscillating section of the actuator 106 and the medium. Therefore, the resonance state of the oscillating section and the medium can be easily obtained after the voltage is applied by the conversion of the voltage applied to the piezoelectric layer 160 into a pulse waveform or rectangular wave. The residual oscillation also deforms even the piezoelectric layer 160 in order to oscillate the oscillating section of the actuator 106. Therefore, the piezoelectric layer 160 generates a counter electromotive force. Its counter electromotive force is detected via the upper portion electrode 164, the lower portion electrode 166, the upper portion electrode terminal 168 and the lower portion electrode terminal 170. A state of the liquid within the liquid container can be detected since a resonance frequency can be specified with the detected counter electromotive force.

[0136]

In general, resonance frequency fs is represented as follows:

$$fs = 1/(2*\pi*(M*C\ act)^{1/2}) \qquad \text{(Expression 1)}$$

wherein M denotes the sum of inertance Mact of the oscillating section and additive inertance M'. Cact denotes compliance of the oscillating section.

[0137]

Fig. 11(C) is a sectional view of the actuator 106 when the ink does not remain in the cavity in the present embodiment. Fig. 12(A) and Fig. 12(B) are the oscillating section of the actuator 106 and the equivalent circuit of the cavity 162 when the ink does not remain in the cavity.

[0138]

Mact denotes the product of the thickness of the oscillating section and the density of the oscillating section that is divided by the area of the oscillating section, and further in detail, as shown in Fig. 12(A), is represented as:

$$Mact = Mpzt + Melectrode1 + Melectrode2 + Mvib \qquad \text{(Expression 2)}$$

Wherein Mpzt is the product of the thickness of the piezoelectric payer 160 in the oscillating layer 160 and the density of the piezoelectric layer 160 that is divided by the area of the piezoelectric layer 160. Melectrode1 denotes the product of the thickness of the upper portion electrode 164 and the density of the upper portion electrode 164 in the oscillating section that is divided by the area of the upper portion electrode 164. Melectrode2 denotes the product of the thickness of the lower portion electrode 166 and the density of the lower portion electrode 166 in the oscillating section that is divided by the area of the lower portion electrode 166. Mvib denotes the product of the thickness of the oscillation plate 176 in the oscillating section and the density of the oscillation plate 176 that is divided by the area of the oscillating region of the oscillation plate 176. However, it is preferable that, in the preset embodiment, the respective areas of the piezoelectric layer 160, the upper portion electrode 164, the lower portion electrode 166 and the oscillating region of the oscillation plate 176 have relationships of being larger and smaller between them as described above, a mutual difference of the area is minute so that Mact can be calculated from the thickness, density and area as the entire oscillation portion. Moreover, in the present embodiment, it is preferable that the portions except for these major portions that are circular portions are minute to the degree of being negligible in the piezoelectric layer 160, the upper portion electrode 164 and the lower portion electrode 166. Therefore, in the actuator 106, Mact denotes the sum of the respective inertance of the oscillating regions out of the upper portion electrode 164, the lower portion electrode 166, the piezoelectric layer 160 and the oscillation plate 176. Moreover, compliance Cact denotes the compliance of the portion formed by the oscillating region out of the upper portion electrode 164, the lower portion electrode 166, the piezoelectric layer 160 and the oscillation plate 176.

[0139]

It should be noted that Fig. 12(A), Fig. 12(B), Fig. 12(D) and Fig. 12(F) show equivalent circuits of the oscillating section of the actuator 106 and the cavity 162. However, in these equivalent circuits, Cact denotes a compliance of the oscillating section of the actuator 106. Cpzt, Celectrode1, Celectrode2 and Cvib denotes respective compliances of the piezoelectric layer 160, the upper portion electrode 164, the lower

portion electrode 166 and the oscillation plate 176 in the oscillating section. Cact is represented by the following equation 3.

[0140]

$$1/Cact = (1/Cpzt) + (1/Celectrode1) + (1/Celectrode2) + (1/Cvib) \quad \text{(Expression 3)}$$

With Expression 2 and Expression 3, Fig. 12(A) can be represented as Fig. 12(B).

[0141]

Compliance Cact denotes a volume capable of receiving the medium generated by deformation occurring at the time when a pressure is added on one unit area of the oscillating section. Moreover, it can be said that compliance Cact denotes the easiness of deformation.

[0142]

Fig. 12(C) shows a sectional view of the actuator 106 in the case when the liquid is sufficiently contained in the liquid container and the liquid is filled on the periphery of the oscillating region of the actuator 106. M' max of the Fig. 12(C) denotes the maximum value of the additive inertance in the case when the liquid is sufficiently contained in the liquid container and the liquid is filled on the periphery of the oscillating region of the actuator 106. M' max is represented by:

[0143]

$$M'\ max = (\pi * \rho /(2*k^3))*(2*(2*k*a)^3/(3*\pi))/(\pi*a^2)^2 \quad \text{(Expression 4)}$$

wherein a denotes a diameter of the oscillating section, ρ denotes a density of the medium and k denotes a wave number.

[0144]

It should be noted that Expression 4 holds in the case when the oscillating region of the actuator 106 is a circular shape of the diameter a. An additive inertance M' denotes a volume indicating the apparent increase in mass of the oscillating section by the action of the medium nearby the oscillating section. As seen in Expression 4, M' max is largely changed by the diameter a of the oscillating section and the density ρ of the medium.

[0145]

Wave number k is represented by:

$k = 2*\pi*fact/c$ (Expression 5)

wherein fact denotes a resonance frequency of the oscillating section at the time when the liquid does not contact, and c denotes a speed of sound that propagates through the medium.

[0146]

[0147]

Fig. 12(D) shows the oscillating section of the actuator 106 and equivalent circuit of the cavity 162 in the case of Fig. 12(C) in which the liquid is sufficiently contained in the liquid container and the liquid is filled on the periphery of the oscillating region of the actuator 106.

[0148]

Fig. 12(E) shows a sectional view of the actuator 106 in the case when the liquid in the liquid container is consumed, the liquid is absent on the periphery of the oscillating region of the actuator 106 but the liquid remains within the cavity 162 of the actuator 106. Expression 4 represents maximum inertance M' max determined from the density ρ of the ink, for example in the case when the liquid container is filled with the liquid. On the other hand, in the case when the liquid within the liquid container is consumed and the liquid on the periphery of the oscillating region of the actuator 106 becomes gas or vacuum while the liquid remains within the cavity 162, M' is represented as follows:

[0149]

$M' = \rho *t/S$ (Expression 6)

wherein t denotes the thickness of the medium involved with oscillation and S denotes an area of the oscillating region of the actuator 106. In the case when the oscillating region is a circular shape of diameter a, $S = \pi*a^2$ holds. Therefore, an additive inertance M' adheres to Expression 4 in the case when the liquid is sufficiently contained in the liquid container and the liquid is filled on the periphery of the oscillating region of the actuator 106. On the other hand, in the case when the liquid is consumed and the liquid on the periphery of the oscillating region of the actuator 106

becomes gas or vacuum while the liquid remains within the cavity 162, the additive inertance M' adheres to Expression 6.

[0150]

Now, as shown in Fig. 12(E), an additive inertance M' in the case when the liquid in the liquid container is consumed, the liquid is absent on the periphery of the oscillating region of the actuator 106 but the liquid remains within the cavity 162 of the actuator 106 is defined as M' cav, and M' cav is discriminated from an additive inertance M' max in the case when the liquid is filled on the periphery of the oscillating region of the actuator 106.

[0151]

Fig. 12(F) shows the oscillating section of the actuator 106 and equivalent circuit of the cavity 162 in the case of Fig. 12(E) in which the liquid in the liquid container is consumed, the liquid is absent on the periphery of the oscillating region of the actuator 106 but the liquid remains within the cavity 162 of the actuator 106.

[0152]

Now, parameters related to a state of the medium are density ρ of the medium and thickness t of the medium in Expression 6. In the case when the liquid is sufficiently contained in the liquid container, the liquid contacts the oscillating section of the actuator 106, and in the case when the liquid is not sufficiently contained within the liquid container, the liquid remains within the cavity, or gas or vacuum contacts the oscillating section of the actuator 106. The liquid on the periphery of the actuator 106 is consumed, and if an additive inertance in the processing for moving from M' max in Fig. 12(C) to M' cav in Fig. 12(E) is defined as M' var, since thickness t of the medium is changed depending on the containing state of the liquid in the liquid container, an additive inertance M' var is changed, and resonance frequency fs is also changed. Therefore, the presence or absence of the liquid in the liquid container can be detected with the resonance frequency fs being specified. Now, as shown in Fig. 12(E), supposing T = d, M' cav is represented with Expression 6 and the depth d of the cavity substituted into t of Expression 6.

[0153]

$$M'\ cav = \rho * d/S \qquad \text{(Expression 7)}$$

[0154]

Moreover, even if the media are different kinds of liquids with each other, since densities ρ are different from the difference of the components, additive inertance M' is changed and resonance frequency fs is also changed. Therefore, the presence or absence of the liquid in the liquid container can be detected with resonance frequency fs being specified. It should be noted that, in the case when only any one of the ink or the air contacts the oscillating section of the actuator 106 and these are not mixed up, the difference of M' can be detected even if a calculation is done with Expression 4.

[0155]

Fig. 13(A) is a graph showing the relationship between a volume of the ink within the ink cartridge and resonance frequency fs of the ink and the oscillating section. Now, the ink will be described as one embodiment of a liquid below. The axis of ordinates indicates resonance frequency fs, and the axis of abscissas indicates a volume of the ink. When the ink components are consistent, resonance frequency fs rises in accordance with the decrease in the remaining ink volume.

[0156]

In the case when the ink is sufficiently contained in the ink container and the ink is filled on the periphery of the oscillating region of the actuator 106, the maximum inertance M' max is a value represented by Expression 4. On the other hand, in the case when the ink is consumed and the ink is not filled on the periphery of the oscillating region of the actuator 106 while the ink remains within the cavity 162, the additive inertance M' var is calculated based on thickness t of the medium with Expression 6. Since t in Expression 6 denotes thickness of the medium involved with the oscillation, the processing in which the ink is step by step consumed can be detected with d of the cavity 162 of the actuator 106 (see Fig. 11(B)) made smaller, specifically, with the substrate 178 made sufficiently thinner (see Fig. 12(C)). There, t ink is defined as thickness of the ink involved with the oscillation, and t ink – max is defined as t ink in M' max. For example, the actuator 106 is arranged on the bottom surface of the ink cartridge in an approximate parallel with the ink liquid level. When the ink is consumed and the ink liquid level arrives at the height lower than the portion of t

ink-max from the actuator 106, M' var is gradually changed according to Expression 6, and resonance frequency fs is gradually changed according to Expression 1. Therefore, as far as the ink liquid level exists within the range of t, the actuator 106 can detect a consuming state of the ink step by step.

[0157]

Moreover, S in Expression 6 is changed according to the liquid level position due to the ink consumption with the oscillating region of the actuator 106 made larger or longer and arranged in a longitudinal direction. Therefore, the actuator 106 can detect the processing in which the ink is consumed step by step. For example, the actuator 106 is arranged on the sidewall of the ink cartridge approximately perpendicular to the ink liquid level. When the ink is consumed and the ink liquid level arrives at the oscillating region of the actuator 106, since the additive inertance M' is reduced accompanied with the lowering of the liquid level, resonance frequency fs is increased step by step according to Expression 1. Therefore, as far as the ink liquid level exists within the range of a radius 2a of the cavity 162 (see Fig. 12(C)), the actuator 106 can detect a consuming state of the ink step by step.

[0158]

Curve X of the Fig. 13(A) denotes the relationship between a volume of the ink contained within the ink cartridge and resonance frequency fs of the ink and the oscillating section in the case when the cavity 162 of the actuator 106 is sufficiently made shallow or in the case when the oscillating region of the actuator 106 is made larger or longer. It can be understood that a resonance frequency fs of the ink and the oscillating section appears to be changed step by step as a volume of the ink is reduced within the ink cartridge.

[0159]

More specifically, the case when the processing in which the ink is consumed step by step can be detected is a case when a liquid and gas having different densities with each other both exist and are involved with the oscillation on the periphery of the oscillating region of the actuator 106. As the ink is consumed step by step, as to the media involved with the oscillation on the periphery of the oscillating region of the actuator 106, the gas is increased while the liquid is reduced. For example, in the case when the actuator 106

is arranged in parallel with the ink liquid level, and when t ink is smaller than t ink-max, the media involved with the oscillation of the actuator 106 include both of the ink and the gas. Therefore, supposing an area S of the oscillating region of the actuator 106, a state of being less than M' max of Expression 4 is represented by additive masses of the ink and the gas as follows:

[0160]

$$M' = M'\ air + M'\ ink = \rho\ air * t\ air/S + \rho\ ink * t\ ink/S \qquad \text{(Expression 8)}$$

wherein M' air denotes inertance of the air, M' ink denotes inertance of the ink, ρ air denotes density of the air, ρ ink denotes density of the ink, t air denotes thickness of the air involved with the oscillation, and t ink denotes thickness of the ink involved with the oscillation. Out of the media involved with the oscillation on the periphery of the oscillating region of the actuator 106, as the liquid is reduced and the air is increased, t air is increased and t ink is reduced in the case when the actuator 106 is arranged in an approximate parallel with the ink liquid level, thereby reducing M' var step by step and a resonance frequency is increased step by step. Therefore, a volume of the ink remaining within the ink cartridge or the consumption volume of the ink can be detected. It should be noted that the reason why Expression 7 is an equation involved only with density of the liquid is because the case when the density of the air is supposed to be negligibly small.

[0161]

In the case when the actuator 106 is arranged approximately perpendicular to the ink liquid level, parallel equivalent circuits (not shown) of the region where the medium involved with the oscillation of the actuator 106 is only the ink and the region where the medium involved with the oscillation of the actuator 106 is only the air out of the oscillating region of the actuator 106 are considered. Supposing that the region where an area of the medium involved with the oscillation of the actuator 106 is only the ink is S ink, and the region where an area of the medium involved with the oscillation of the actuator 106 is only the air is S air:

[0162]

$$1/M' = 1/M'\ air + 1/M'\ ink = S\ air/(\rho\ air * t\ air) + S\ ink/(\rho\ ink * t\ air) \qquad \text{(Expression 9)}$$

[0163]

It should be noted that Expression 9 is applied in the case when the ink is not held in the cavity of the actuator 106. In the case when the ink is held in the cavity of the actuator 106, it is possible to calculate with Expression 7, Expression 8 and Expression 9.

[0164]

On the other hand, in the case when the substrate 178 is thick, specifically, depth d of the cavity 162 is deep, d is comparatively close to the thickness t ink – max of the medium, or in the case when an actuator whose oscillating region is very small compared to the height of the liquid container is employed, it is actually detected whether or not the ink liquid level is higher or lower than the mounting position of the actuator, rather than the processing in which the ink is reduced is detected step by step. In other words, the presence or absence of the ink in the oscillating region of an actuator is detected. For example, curve Y in Fig. 13(A) denotes the relationship between a volume of the ink within the ink cartridge in the case of a small circular oscillating region and resonance frequency fs of the ink and the oscillating section. In the range of a volume of the ink Q prior to and after the ink liquid level within the ink cartridge passes through the mounting position of the actuator, the appearance that resonance frequency fs of the ink and the oscillating section is drastically changed is indicated, thereby being capable of detecting whether or not the predetermined volume of the ink within the ink cartridge remains.

[0165]

Fig. 13(B) shows the relationship between the density of the ink in curve Y in Fig. 13(A) and resonance frequency fs of the ink and the oscillating region. Ink is exemplified as a liquid. As shown in Fig. 13(B), as the density of the ink is increased, the additive inertance is increased. Therefore, a resonance frequency fs is lowered. Specifically, resonance frequencies fs are different depending upon the kinds of ink. Therefore, when the ink is refilled, it is checked whether or not the ink having a different density is mixed with resonance frequency fs being measured.

[0166]

Specifically, an ink cartridge containing different kinds of ink with each other

can be identified.

[0167]

Subsequently, conditions in which a state of the liquid can be precisely detected when the size and shape of the cavity are set so that the liquid remains within the cavity 162 of the actuator 106 even if the liquid within the liquid container is hollow will be described in detail below. If the actuator 106 can detect a state of the liquid in the case when the liquid is filled within the cavity 162, it can detect a state of the liquid even in the case when the liquid is not filled within the cavity 162.

[0168]

Resonance frequency fs is a function of inertance M. Inertance M is the sum of inertance M act and additive inertance M'. There, the additive inertance is involved with a state of the liquid. Additive inertance M' is a volume indicating an apparent increase in mass of the oscillating section by the action of the medium nearby the oscillating section. Specifically, that is referred to an increment in mass of the oscillating section with the medium apparently absorbed by the oscillation of the oscillating section.

[0169]

Accordingly, in the case when M' cav is larger than M' max in Expression 4, the apparently absorbed medium is all the liquid remaining within the cavity 162. Therefore, this state is the same as that in which the liquid container is filled with the liquid. At that time, since M' is not changed, resonance frequency fs is not changed, either. Therefore, the actuator 106 cannot detect a state of the liquid within the liquid container.

[0170]

On the other hand, in the case when M' cav is smaller than M' max in Expression 4, the apparently absorbed media are the remaining liquid within the cavity 162 and the gas or vacuum within the liquid container. At that time, since M' is changed differently from a state in which the liquid is filled within the liquid container, resonance frequency fs is changed. Therefore, the actuator 106 can detect a state of the liquid within the liquid container.

[0171]

Specifically, in the case when the liquid within the liquid container is in a state

of being empty and the liquid remains within the cavity 162 of the actuator 106, the conditions in which the actuator 106 can precisely detect a state of the liquid is that M' cav is smaller than M' max. It should be noted that the conditions M' max > M' cav in which the actuator 106 can precisely detect a state of the liquid is not involved with the shape of the cavity 162.

[0172]

M' cav is mass of the liquid having an approximate equivalent to the volume of the cavity 162. Accordingly, from the inequality of M' max > M' cav, the conditions in which the actuator 106 can precisely detect a state of the liquid can be represented as conditions for the volume of the cavity 162. For example, supposing that a diameter of the opening 161 of the circular cavity 162 is a and the depth of the cavity 162 is d,

[0173]

$$M' \max > \rho * d / \pi a^2 \qquad \text{(Expression 10)}$$

Expression 10 is expanded, and the following conditions are found:

[0174]

$$a/d > 3 * \pi/8 \qquad \text{(Expression 11)}$$

It should be noted that Expression 10 and Expression 11 hold as far as the shape of the cavity 162 is circular. When the expression of M' max in the case when it is not circular is employed and its area is substituted into πa^2 in Expression 10, the relationship between dimensions such as a width and a length of the cavity and the depth of the cavity is led.

[0175]

Therefore, the actuator 106 having the cavity 162 whose dimensions are the radius a of the opening 161 and the depth d of the cavity 162 that satisfies Expression 11 can detect a state of the liquid without malfunctions even in the case when the liquid within the liquid container is empty and the liquid remains within the cavity 162.

[0176]

Since inertance M' has influence on an acoustic impedance property, it can be said that a method of measuring a counter electromotive force generated by the actuator 106 due to the residual oscillation detects at least a change in acoustic impedance.

[0177]

Moreover, according to the present embodiment, the actuator 106 generates an oscillation and measures a counter electromotive force generated by the actuator 106 due to the subsequently occurring residual oscillation. However, it is not always necessary that the oscillating section of the actuator 106 applies the oscillation to the liquid by its own oscillation due to the drive voltage. Specifically, if the oscillating section itself does not oscillate, the piezoelectric layer 160 is deflected and deformed by the oscillation along with the liquid in a certain range in which the oscillating section contacts the liquid. This residual oscillation causes the piezoelectric layer 160 to generate a counter electromotive force voltage and transmits its counter electromotive force voltage to the upper portion electrode 164 and the lower portion electrode 166. A state of the medium may be detected with this phenomenon being utilized. For example, in an ink jet recording apparatus, a state of the ink cartridge or the ink within it may be detected with the utilization of the oscillation that occurs on the periphery of the oscillating section of an actuator generated by the oscillation due to the reciprocating movement of the carriage by the scanning of the recording head at the time when printing is done.

[0178]

Fig. 14(A) and Fig. 14(B) show a waveform of the residual oscillation and a method of measuring the residual oscillation of the actuator 106 after the actuator 106 is made vibrated. The moving up and down of the ink liquid level in the mounting position level of the actuator 106 within the ink cartridge can be detected with a change in frequency of the residual oscillation and a change in amplitude after the actuator 106 oscillates. In Fig. 14(A) and Fig. 14(B), the axis of ordinates indicates a voltage of a counter electromotive force generated by the residual oscillation of the actuator 106 and the axis of abscissa indicates time. A waveform of an analogue signal of voltage as shown in Fig. 14(A) and Fig. 14(B) is generated by the residual oscillation of the actuator 106. Subsequently, the analogue signal is converted into a digital numeric value corresponding to the frequency of the signal.

[0179]

In the embodiment shown in Fig. 14(A) and Fig. 14(B), the presence or absence of

the ink is detected by the measurement of a time period generated by four pieces of pulse from the fourth pulse to the eighth pulse of the analogue signal.

[0180]

More specifically, after the actuator 106 oscillates, the times that the reference voltage previously set crosses from the lower voltage side to the higher voltage side are counted. A digital signal in the range from the fourth count to the eighth count is defined as High, and a time period spanning from the fourth count to the eighth count is measured with the predetermined clock pulse.

[0181]

Fig. 14(A) shows a waveform at the time when the ink liquid level exists at a higher level than the mounting position level of the actuator 106. On the other hand, Fig. 14(B) shows a waveform at the time when the ink is absent at the mounting position level of the actuator 106. Comparing Fig. 14(A) and Fig. 14(B), the waveform in Fig. 14(A) is longer than the waveform in Fig. 14(B) in the time span from the fourth count to the eighth count. In other words, time spans from the fourth count to the eighth count are different depending on the presence or absence of the ink. An ink consumption state can be detected with these differences of the time spans being utilized. The reason why the counting from the fourth count of the analogue waveform is because it should be started after the oscillation of the actuator 106 is stable. The counting from the fourth count is only an example, and the counting may be started from an optional ordinal number of count. Here, a signal from the fourth count to the eighth count is detected, and a time span from the fourth count to the eighth count is measured with a predetermined clock pulse, thereby finding a resonance frequency. A clock pulse is preferably a pulse of a clock equivalent to a clock for controlling a semiconductor and the like mounted on the ink cartridge. It should be noted that it is not necessary to measure a time span until the eighth count and it may count until an optional ordinal number of count. In Fig. 14, a time span from the fourth count to the eighth count is measured. However, a time span within the different counts of interval may be measured according to a circuit configuration in which the frequency is detected.

[0182]

For example, in the case when the quality of the ink is stable and the variation of the amplitude between the peaks is small, a resonance frequency may be found with a time span detected from the fourth count to the sixth count in order to speed up the detection rate. Moreover, in the case when the quality of the ink is unstable and the variation of the amplitude of the pulse is large, a time span from the fourth count to the twelfth count may be detected in order to precisely detect the residual oscillation.

[0183]

Moreover, as another embodiment, the wave number of a voltage waveform of a counter electromotive force in the predetermined period may be counted (not shown). Also with this method, a resonance frequency can be found. More specifically, after the actuator 106 oscillates, a digital signal is made High only in the predetermined period and the predetermined reference voltage crosses from the lower voltage side to the higher voltage side. The presence or absence of the ink can be detected with its number of count being measured.

[0184]

Furthermore, as it is understood from the comparison between Fig. 14(A) and Fig. 14(B), the amplitudes of the counter electromotive forces are difference in the case when the ink is filled within the ink cartridge and in the case when the ink is absent within the ink cartridge. Accordingly, an ink consumption state within the ink cartridge may be detected with an amplitude of a counter electromotive force being measured without finding a resonance frequency. More specifically, for example, the reference voltage is set between the vertex of a counter electromotive force in Fig. 14(A) and the vertex of a counter electromotive force in Fig. 14(B). After the actuator 106 oscillates, a digital signal is made High, and in the case when the counter electromotive force crosses the reference voltage, the absence of the ink is determined. In the case when the counter electromotive force does not cross the reference voltage, the presence of the ink is determined.

[0185]

Fig. 15 is a perspective view showing a configuration integrally forming the actuator 106 as a mounting module body 100. The module body 100 is equipped on the

predetermined location of the container body 1. The module body 100 is configured so that it detects a consumption state of the liquid within the container body 1 by detecting at least a change in acoustic impedance in the ink liquid. The module body 100 of the present embodiment has a liquid container mounting portion 101 for mounting the actuator 106 on the container body 1. The liquid container mounting portion 101 is configured such that a circular cylinder portion 116 containing the actuator 106 for oscillating with a drive signal is mounted on the base 102 whose plane is approximately rectangular. The module body 100 is mounted on the internal wall in the container of the ink cartridge. Lead wires 104a and 104b are connected to the electrode terminals of the actuator 106 and extend to the external via the sidewall of the ink cartridge, thereby being capable of conducting an electric signal detected by the actuator 106 to the external of the ink cartridge.

[0186]

Fig. 16 is a perspective view showing another embodiment of a module body. In a module body 400 of the present embodiment, a piezoelectric device mounting portion 405 is formed on the liquid container mounting portion 401. In the liquid container mounting portion 401, the cylindrical circular cylinder portion 403 is formed on the base 402 whose plane is approximately square and rounded off. Furthermore, the piezoelectric device mounting portion 405 includes a planar factor 406 stood on the circular cylinder portion 403 and the convex 413. The actuator 106 is arranged on the convex portion 413 provided on the sidewall of the planar factor 406.

[0187]

Fig. 17 shows still another embodiment of a module body. Similarly to the module body 100 shown in Fig. 15, a module body 500 in Fig. 17 includes the liquid container mounting section 501 having a base 502 and a circular cylinder portion 503. The module body 500 further has the lead wires 504a and 504b, the actuator 106, the film 508 and the plate 510. In the base 502 included in the liquid container mounting section 501, the opening portion 514 is formed in the center portion so as to be able to contain the lead wires 504a and 504b, and the convex portion 513 is formed so as to be capable of containing the actuator 106, the film 508 and the plate 510. The actuator 106 is fixed on the piezoelectric device mounting section 505 via the plate 510. Therefore,

the lead wires 504a and 504b, the actuator 106, the film 508 and the plate 510 are integrally mounted on the liquid container mounting section 501. In the module body 500 of the present embodiment, the circular cylinder portion 503 provided on the upper surface in a vertically slanting manner is formed on the base 502 whose plane is square and rounded off. The actuator 106 is arranged on the convex portion 513 provided on the circular cylinder portion 503 in a vertically slanting manner.

[0188]

The tip of the module body 500 is slanting, and the actuator 106 is mounted on its slanting surface. Therefore, when the module body 500 is mounted on the bottom portion or sidewall of the container body 1, the actuator 106 has a slope with respect to the vertical direction of the container body 1. The slanting angle of the tip of the module body 500 is preferably between approximately 30° and 60° in consideration of detection performance.

[0189]

The module body 500 is mounted on the bottom wall, sidewall or top wall of the container body 1 so that the actuator 106 is arranged within the container body 1. In the case when the module body 500 is mounted on the side portion of the container body 1, the actuator 106 is mounted on the container body 1 so that the actuator 106 is slanting and facing toward the upper side, lower side or lateral side. On the other hand, in the case when the module body 500 is mounted on the bottom portion 1a of the container body 1, the actuator 106 is mounted on the container body 1 so that the actuator 106 is slanting and facing toward the ink supply opening of the container body 1.

[0190]

Fig. 18 shows an embodiment equipped with a mold structure 600 containing the actuator 106. In the present embodiment, as one of the mounting structures, the mold structure 600 is used. The mold structure 600 has the actuator 106 and a mold section 364. The actuator 106 and the mold section 364 are integrally molded. The mold section 364 is molded with a plastic material such as silicon resin or the like. The mold section 364 has a lead wire 362 inside. The mold section 364 is formed so that it has two pieces of legs extending from the actuator 106. The ends of the two pieces of the legs of the mold

section 364 are formed in a semi-sphere shape in order that the mold section 364 and the container body 1 are fixed in a fluid-tight manner. The mold section 364 is mounted on the container body 1 so that the actuator 106 projects into the interior of the container body 1 and the oscillating section of the actuator 106 contacts the ink within the container body 1. The upper electrode 164, the piezoelectric layer 160 and the lower electrode 166 of the actuator 106 are protected from the contact with the ink by the mold section 364.

[0191]

The ink does not easily leak from the container body 1 since a sealing structure 372 is not required between the mold section 364 and the container body 1, which are protected by the mold structure 600 in Fig. 18. Moreover, since the form is such that the mold structure 600 does not project from the external of the container body 1, the actuator 106 can be protected from the contact with the external. When the ink cartridge is swung, the ink is attached on the upper surface of the container body 1 and the ink running from the upper surface contacts the actuator 106, thereby possibly causing the occurrence that the actuator 106 erroneously operates. As for the mold structure 600, the actuator 106 does not erroneously operate by the ink running from the upper surface of the container body 1 since the mold section 364 protects the actuator 106.

[0192]

In the present embodiment, the mold structure 600 is mounted on the apex wall 1040 located at the upper portion with respect to the liquid level of the ink within the container body 1. Moreover, the oscillation region of the actuator 106 is located at the slightly lower position with respect to the liquid level of the liquid when the liquid is not consumed. Therefore, immediately after the ink cartridge is used and the ink is beginning to be consumed, the oscillation region of the actuator 106 detects the gas. Therefore, the actuator 106 is not necessarily mounted on the sidewall of the container body 1.

[0193]

It should be noted that the mold structure 600 is formed so that the oscillation region of the actuator 106 is located at the slightly upper position with respect to the liquid level of the ink, thereby being capable of obtaining the similar effect of the ink cartridge according to the embodiment in Fig. 2.

[0194]

Fig. 19(A) is an enlarged sectional view of a circuit substrate 610 provided and arranged on the ink cartridge, and Fig. 19(B) is a perspective view seen from the front thereof. The circuit substrate 610 according to the present embodiment, the semiconductor storage means 7 and the actuator 106 are integrally formed. The circuit substrate 610 can be provided and arranged in the ink cartridge instead of the actuator 106 in the embodiments in Fig. 1 through Fig. 7. As shown in Figs. 19(A) and 19(B), the semiconductor storage means 7 is formed at the upper position of the circuit substrate 610, and the actuator 106 is formed at the lower position of the semiconductor storage means 7 in the identical circuit substrate 610. In the circuit substrate 610, a plurality of caulking sections 616 are formed for mounting the circuit substrate 610 on the ink cartridge. The circuit substrate 610 is fixed on the ink cartridge with the caulking section 616. It is formed that the external terminal 612 of the semiconductor storage means 7 and the external terminal 107 of the actuator 106 can be electrically connected with the external via the sidewall of the ink cartridge. The semiconductor storage means 7 can electrically receive and deliver the electrical signal from and to the external with the external terminal 612 and the external terminal 107 being electrically connected with the external.

[0195]

The semiconductor storage means 7 may be, for example, constituted by a rewritable semiconductor memory such as EEPROM or the like. Since the semiconductor storage means 7 and the actuator 106 are formed on the same circuit substrate 610, when the actuator 106 and the semiconductor storage means 7 are mounted on the ink cartridge, the mounting step can be done only once to be completed. Moreover, the working step during the manufacturing and recycling of an ink cartridge is simplified. Furthermore, since the number of items of the parts is reduced, the manufacturing cost of the ink cartridge is reduced.

[0196]

The actuator 106 detects the consumption state of the ink within the ink cartridge. The semiconductor storage means 7 stores the information such as the ink residual volume that the actuator 106 has detected, the characteristic value that the characteristic value detecting section 810 has detected and the results that the characteristic

value judging section 820 has judged, and can act as the storage section 850. Preferably, the semiconductor storage means 7 stores the predetermined condition that the characteristic value of the actuator 106 should satisfy and the past errors and the instructions. Furthermore, a resonance frequency is previously stored in the semiconductor means 7 when the ink is full or ended, dispersion may be corrected with the data of a resonance frequency being read on the side of the ink jet recording apparatus when the ink residual volume is detected.

[0197]

Fig. 20 shows an embodiment of an ink cartridge and an ink jet recording apparatus employing the actuator 106 shown in Fig. 11. The multiple ink cartridges 180 are mounted on an ink jet recording apparatus having the multiple ink inlet portions 182 and the holders 184 corresponding to the respective ink cartridge 180. The multiple ink cartridges 180 contain the respective different kinds of ink, for example, ink of different colors. The actuator 106 that is a means for detecting at least acoustic impedance is mounted on the respective bottom surfaces of the multiple ink cartridges 180. An ink remaining volume within the ink cartridge 180 can be detected with the actuator 106 mounted on the ink cartridge 180.

[0198]

Fig. 21 shows the details of the periphery of a head portion of an ink jet recording apparatus. The ink jet recording apparatus has an ink inlet portion 182, a holder 184, a head plate 186 and a nozzle plate 188. Multiple nozzles 190 for injecting the ink are formed on the nozzle plate 188. The ink inlet portion 182 has an air supply opening 181 and an inlet 183. The air supply opening 181 supplies air to the ink cartridge 180. The ink inlet 183 introduces the ink from the ink cartridge 180. The ink cartridge 180 has an air inlet 185 and an ink supply opening 187. The air supply inlet 185 introduces the air from the air supply opening 181 of the air inlet portion 182. The ink supply opening 187 supplies the ink to the ink inlet 183 of the ink inlet portion 182. The ink cartridge 180 introduces the air from the ink inlet portion 182, thereby urging the ink supply from the ink cartridge 180 to the ink inlet portion 182. The holder 184 communicates the ink supplied from the ink cartridge 180 via the ink inlet portion 182 to the head plate 186. The ink is supplied from an ink cartridge 180 to the head via an ink introduction section

182, and discharged from the nozzle to the recording medium. Owing to this, the ink jet recording apparatus performs printing on the recording medium. It should be noted that the other portions are shown in Fig. 20 and Fig. 21 with the actuator 106 being omitted.

[0199]

Up to this point, the case when the actuator 106 is attached to the ink cartridge mounted on the cartridge or to the cartridge in the case when the ink cartridge is separate from the carriage has been described. However, the actuator 106 may be mounted on the ink cartridge mounted on the ink jet recording apparatus integrated with the carriage and mounted on it with the carriage. Furthermore, the actuator 106 may be mounted on the ink cartridge, which is separate from the carriage and has an off carriage method of supplying the ink to the cartridge via a tube or the like. Still furthermore, the actuator that is used in the present invention may be mounted on an ink cartridge integrally configured with the recording head in an exchangeable manner.

[0200]

Up to this point, the embodiments of the present invention have been described. However, the technical scope of the present invention is not limited to the scope described in the above-mentioned embodiments. A variety of modifications can be added to the above-described embodiments. It is obvious from the recitation of the scope of the claims that the modes to which such modifications or improvements have been added can also be included in the technical scope of the present invention.

[0201]

[Effect of the Invention]

According to the present invention, it can be judged whether or not the piezoelectric device is normally operated, and further, an operation of the ink jet recording apparatus can be controlled based on the judgment of whether the piezoelectric device is normally operated or not.

[0202]

Moreover, according to the present invention, during the manufacturing of a liquid container and after the manufacturing of the same, it can be confirmed that a liquid of the predetermined volume is contained within the liquid container.

[0203]

Furthermore, according to the present invention, it can be detected that the predetermined volume of the ink is not contained within the liquid container due to the defect of the liquid container and/or the piezoelectric device, and further, an operation of the ink jet recording apparatus can be controlled based on the detected results of the volume of the ink.

[0204]

Furthermore, according to the present invention, the gradient of the liquid container can be detected in the case when the liquid container is not properly mounted or the like, and further, an operation of the ink jet recording apparatus can be controlled based on the detected results of the volume of the ink.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a view showing an ink cartridge used for mono color ink, for example, black color ink as one embodiment of a liquid container.

[Fig. 2]

Fig. 2 is a view showing an ink cartridge as another embodiment of the liquid container.

[Fig. 3]

Drawings in Fig. 3 are views showing ink cartridges as other embodiments of the liquid container.

[Fig. 4]

Fig. 4 is a sectional view showing an ink cartridge in the traverse direction as another embodiment of the liquid container.

[Fig. 5]

Fig. 5 is a view showing an ink cartridge as another embodiment of the liquid container.

[Fig. 6]

Fig. 6 is a perspective view seen from the backside showing an ink cartridge

containing a plurality of kinds of ink as another embodiment of the liquid container.

[Fig. 7]

Fig. 7 is a sectional view showing the major sections of an ink jet recording apparatus in which the ink cartridge is used as one embodiment.

[Fig. 8]

Fig. 8 is a block diagram showing a controller of an ink jet recording apparatus as one embodiment.

[Fig. 9]

Fig. 9 is a flowchart showing a method of controlling an ink jet recording apparatus on which the ink cartridge shown in Fig. 1 is mounted.

[Fig. 10]

Fig. 10 is a flowchart showing a method of controlling an ink jet recording apparatus on which the ink cartridge shown in Fig. 1 is mounted.

[Fig. 11]

Drawings in Fig. 11 are views showing an actuator 106 in detail, which is one example of a piezoelectric device.

[Fig. 12]

Fig. 12 is a view showing an actuator 106 in details, which is one example of a piezoelectric device, and an equivalent circuit.

[Fig. 13]

Drawings in Fig. 13 are graphical representations showing the relationship between the volume of ink within an ink cartridge and a resonance frequency of ink and an oscillating section.

[Fig. 14]

Drawings in Fig. 14 are graphical representations showing a method of measuring a waveform of the residual oscillation of an actuator and the residual oscillation after the actuator is made oscillated.

[Fig. 15]

Fig. 15 is a perspective view showing a configuration in which the actuator 106 is integrally formed as a module body.

[Fig. 16]

Fig. 16 is a perspective view showing another example of a module body.

[Fig. 17]

Drawings in Fig. 17 are views showing still another example of a module body.

[Fig. 18]

Fig. 18 is a view showing one example of a mold structure equipped with an actuator 106.

[Fig. 19]

Drawings in Fig. 19 are views showing still another example of an ink cartridge.

[Fig. 20]

Fig. 20 is a view showing an ink cartridge and an ink jet recording apparatus in which the actuator 106 shown in Fig. 11 is used as one embodiment.

[Fig. 21]

Fig. 21 is a view showing the head section and its peripherals of an ink jet recording apparatus as one embodiment.

[Explanation of Numerical Symbols]

106	Actuator
107, 109, 612	External terminal
111	Lead wire
180	Ink cartridge
700	Carriage
702	Recording head
712	Cap
716	Carriage drive motor
722	Carriage motor control means
720	Piezoelectric device control means
750	Control section
810	Characteristic value detecting section

820	Characteristic value judging section
830	Ink consumption volume measuring section
840	Output section
850	Storage section
1010, 1012	Supply opening forming sidewall
1020	Intervening sidewall
2000	Panel
2500	External output terminal
3000	Host computer

DRAWINGS

[Fig. 8]

720	Piezoelectric device control means
722	CR motor control means
724	Head control means
728	Pump control means
742	Head drive means
744	Pump drive means
810	Characteristic value detecting section
820	Characteristic value judging section
830	Ink consumption volume measuring section
840	Output section
850	Storage section

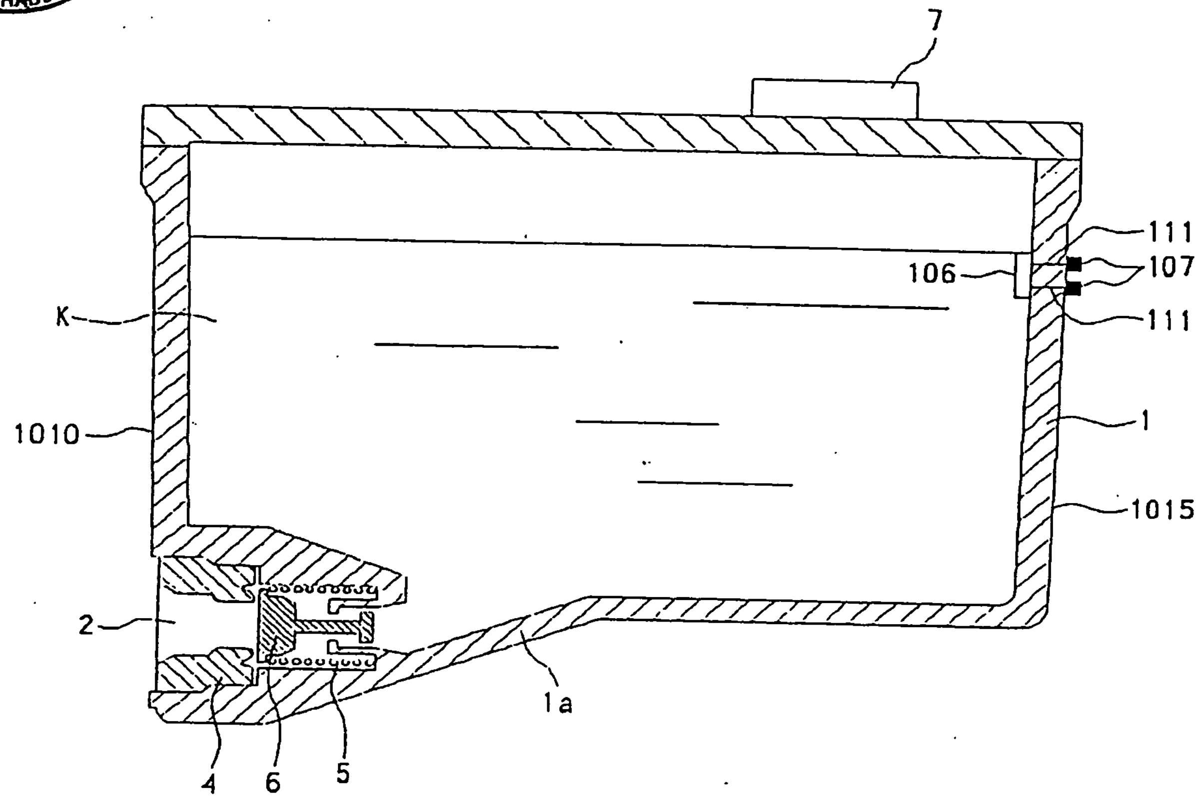


Fig. 1

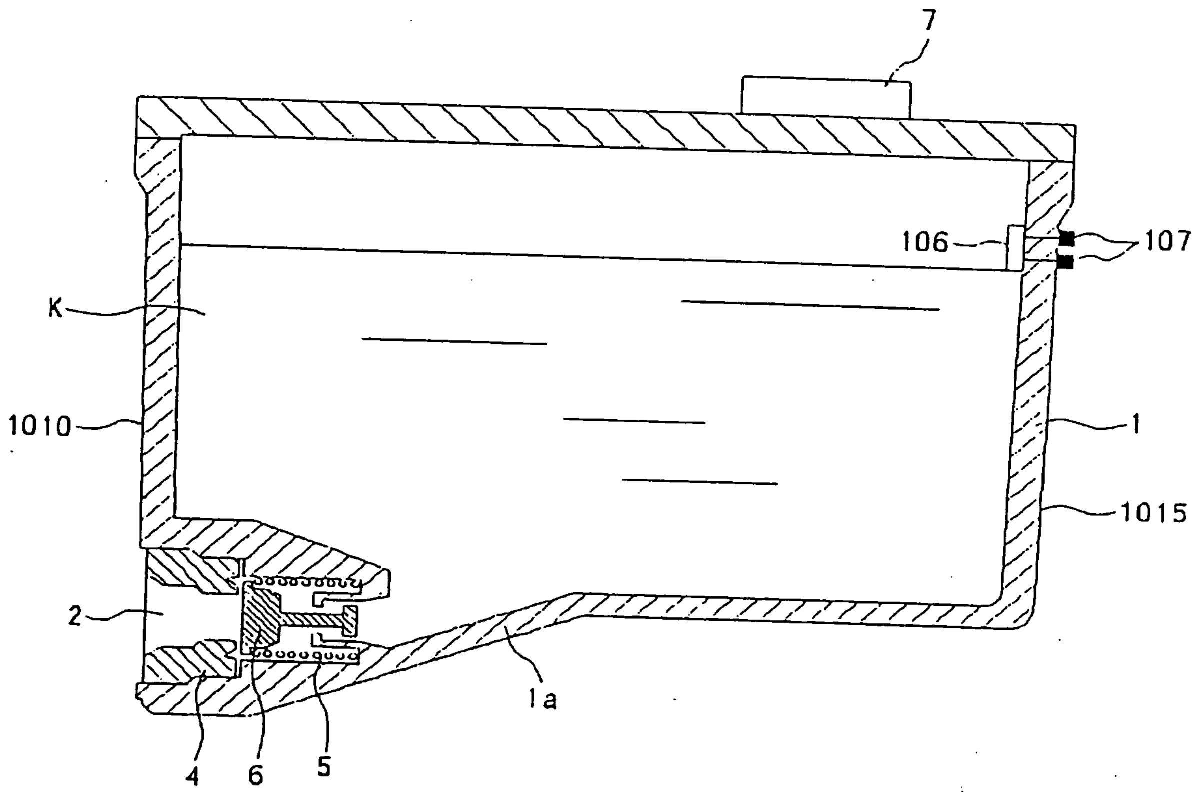


Fig. 2

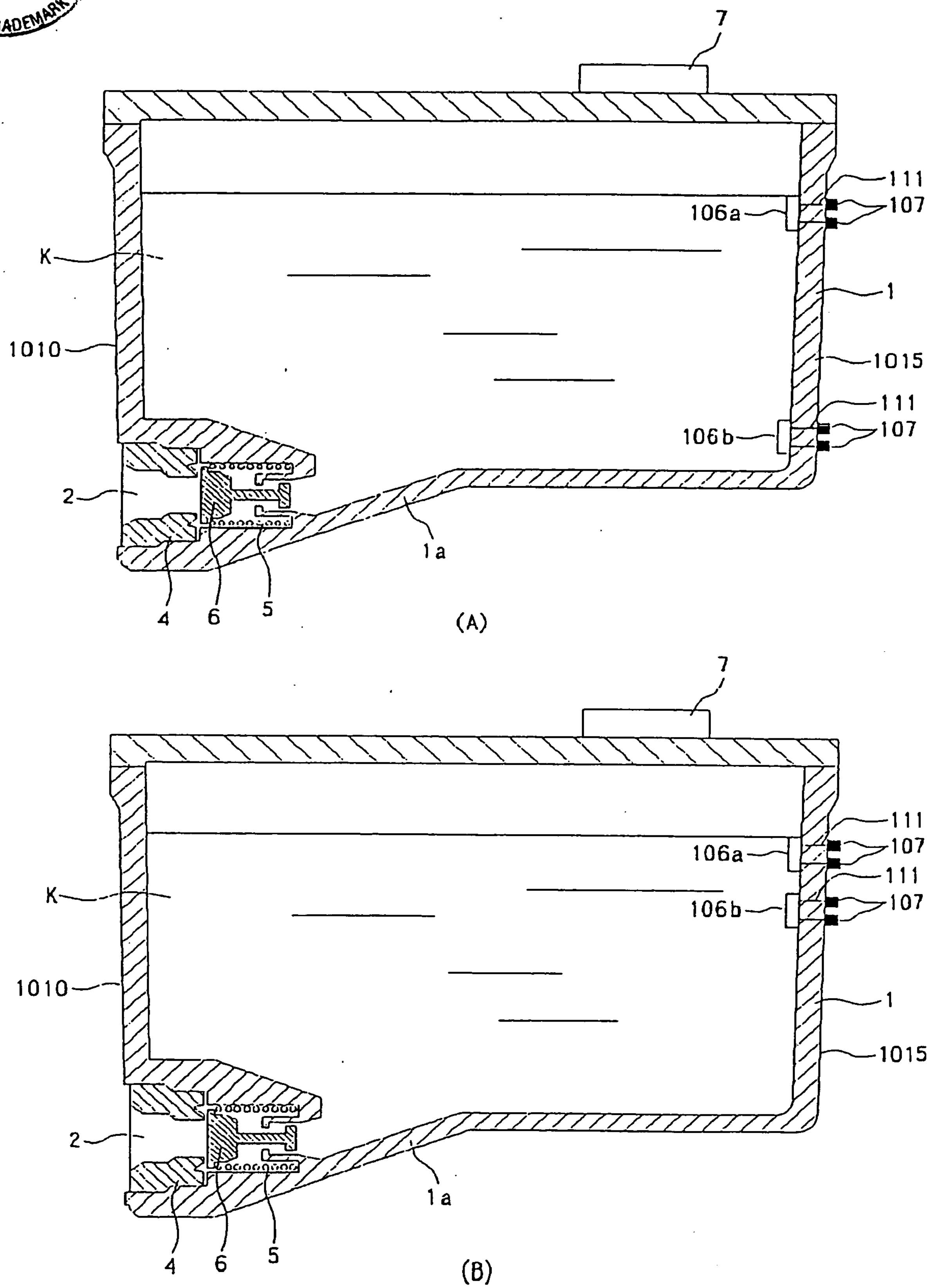

7
111
107
106a
K
1
1010
1015
111
106b
107
2
1a
4
6
5
(A)
7
111
106a
107
111
K
106b
107
1010
1
1015
2
1a
4
6
5
(B)

Fig. 3

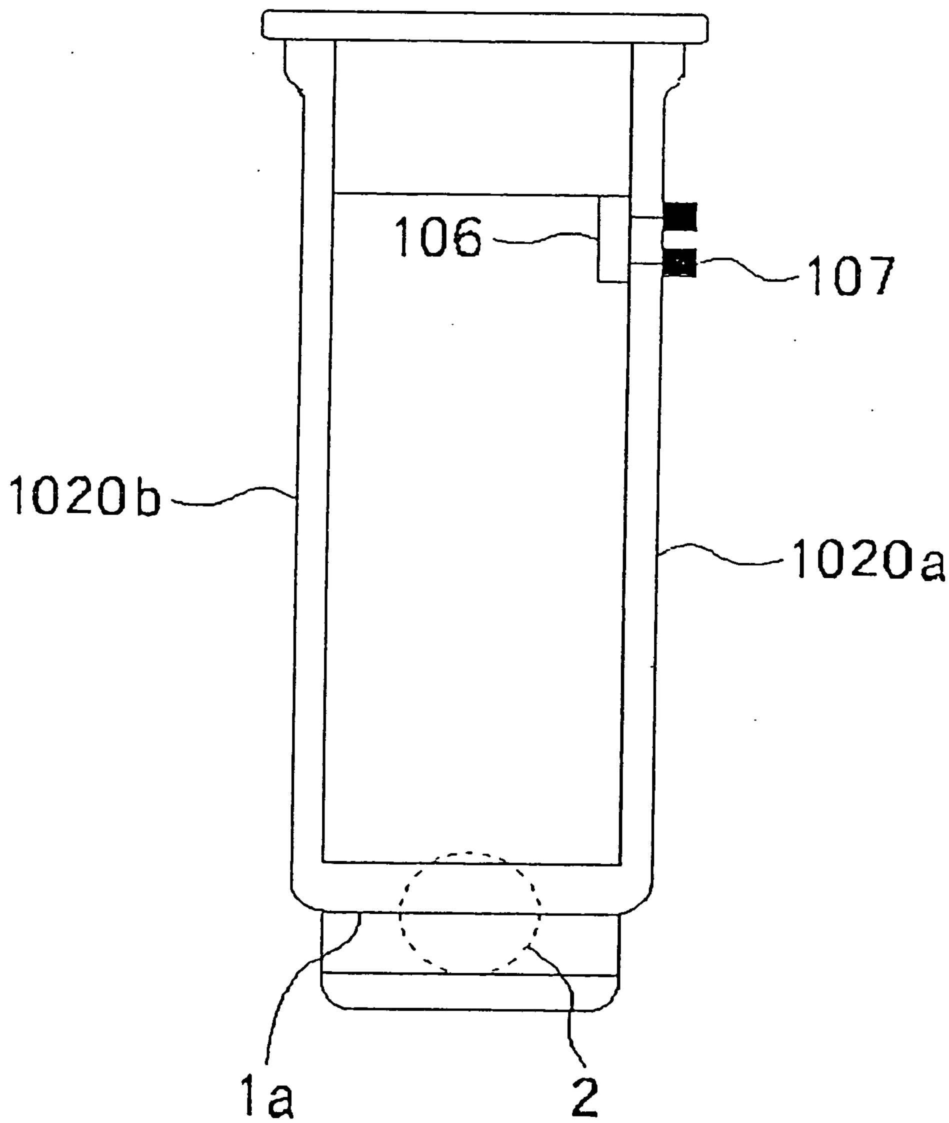


Fig. 4

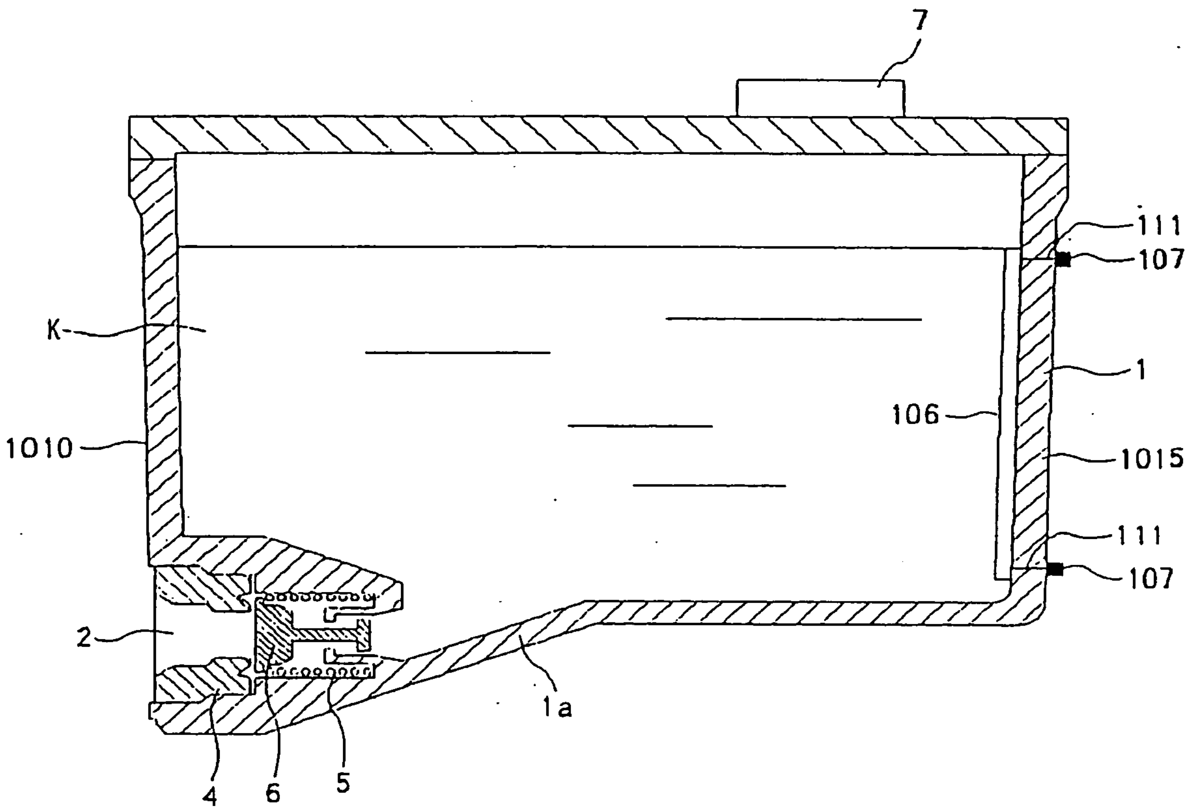


Fig. 5

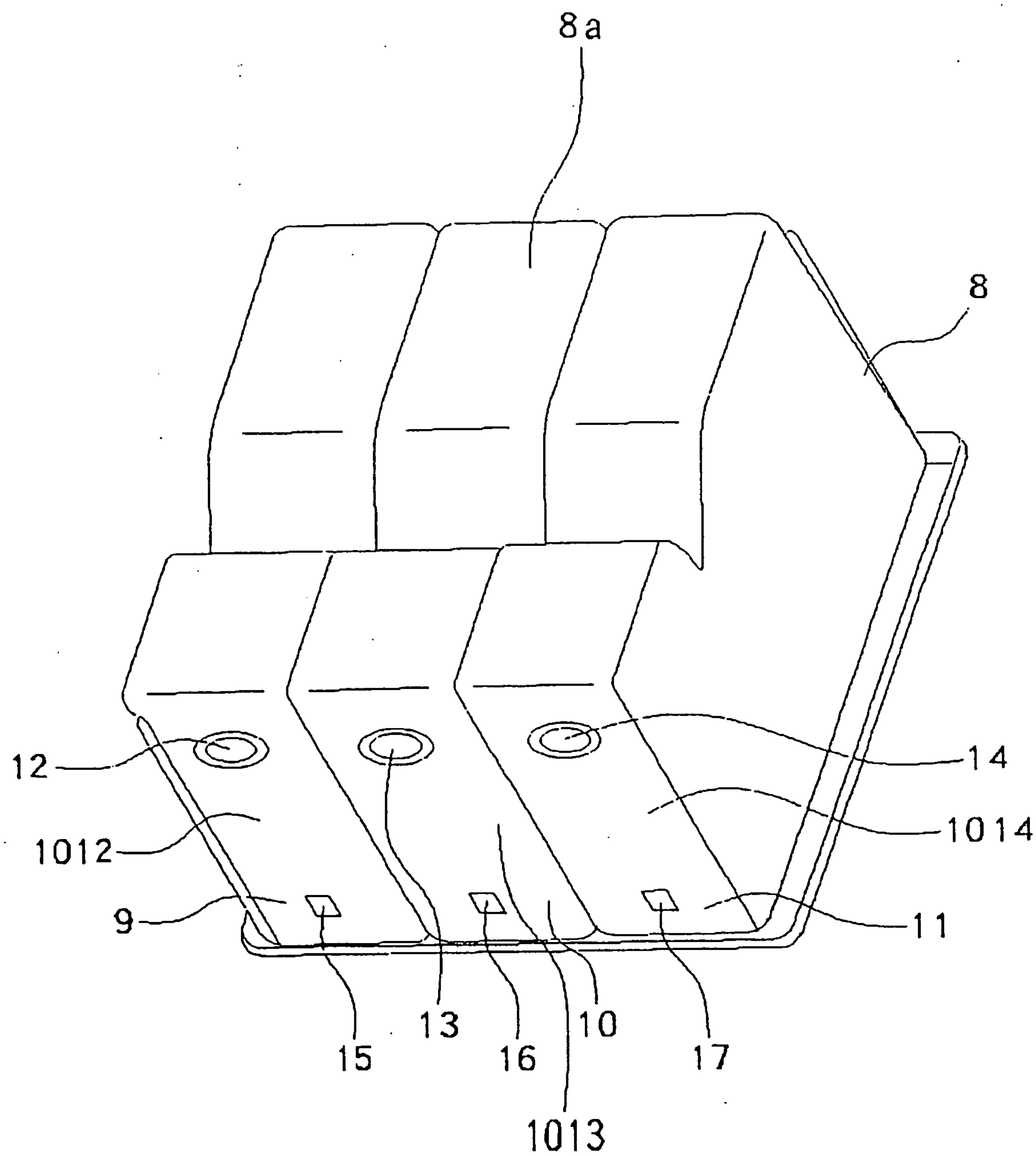


Fig. 6

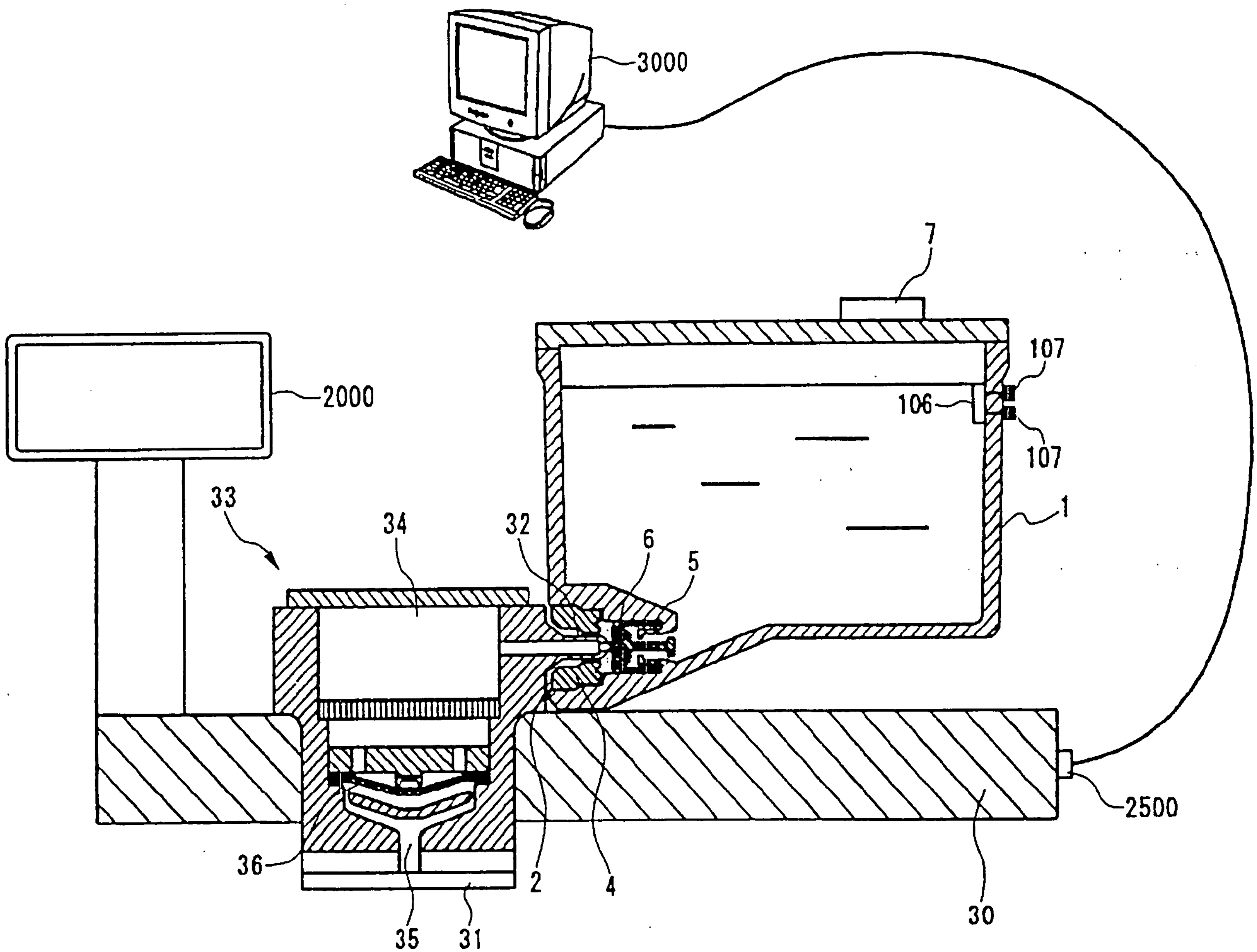
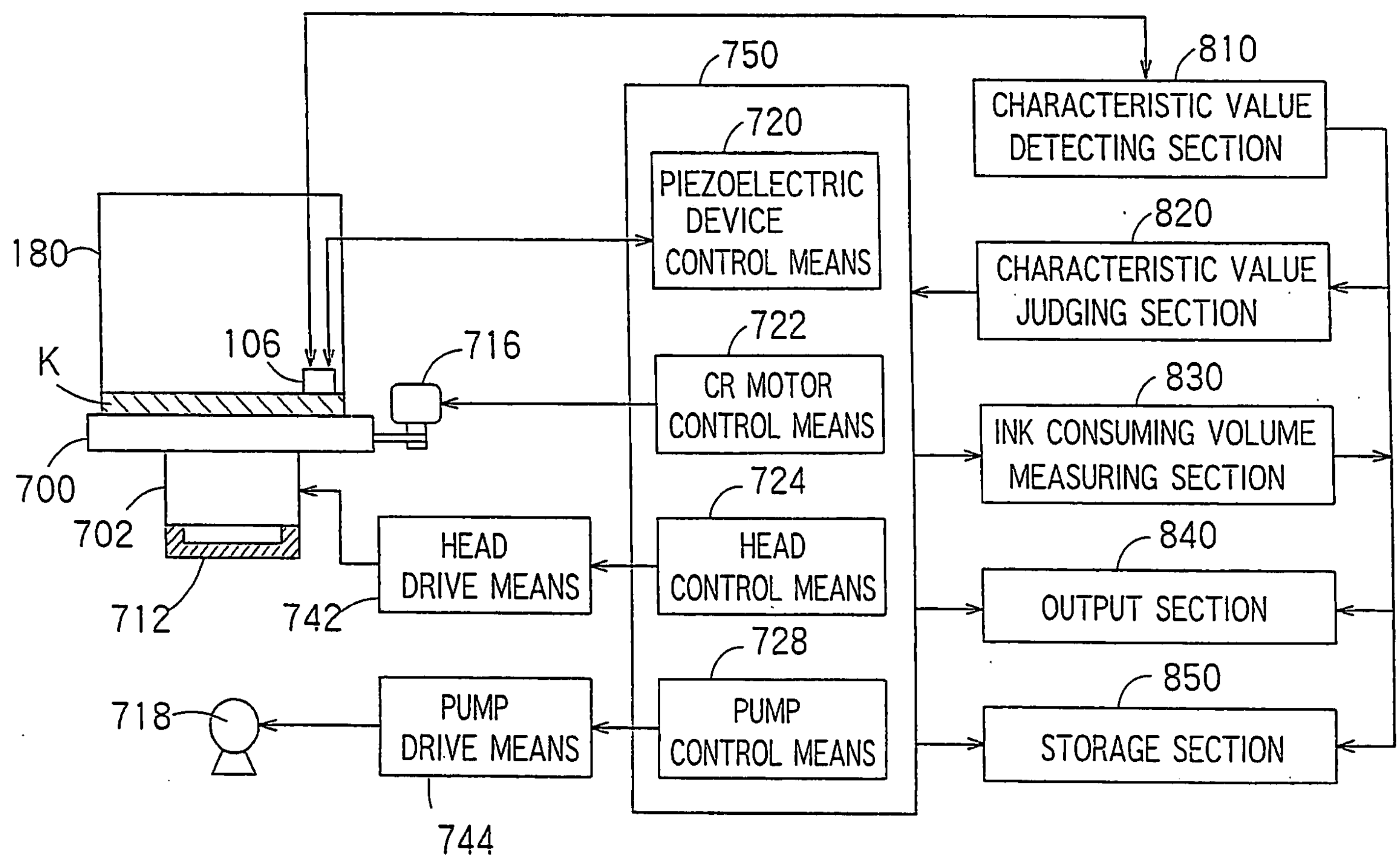


Fig. 7



750
810
CHARACTERISTIC VALUE DETECTING SECTION
720
PIEZOELECTRIC DEVICE CONTROL MEANS
820
CHARACTERISTIC VALUE JUDGING SECTION
180
106
716
K
722
CR MOTOR CONTROL MEANS
830
INK CONSUMING VOLUME MEASURING SECTION
700
702
724
HEAD DRIVE MEANS
HEAD CONTROL MEANS
840
OUTPUT SECTION
712
742
728
850
718
PUMP DRIVE MEANS
PUMP CONTROL MEANS
STORAGE SECTION
744

Fig. 8

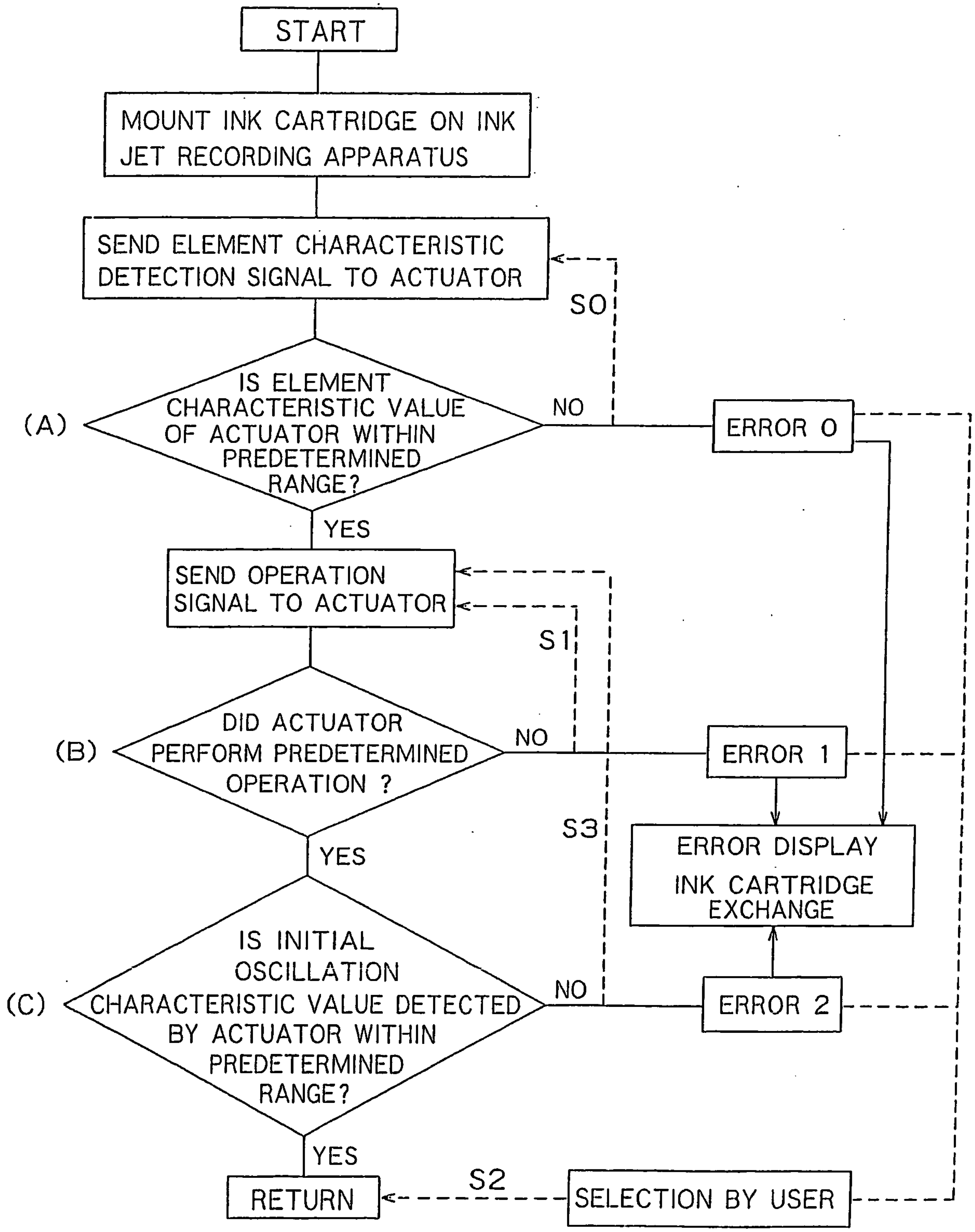

START
MOUNT INK CARTRIDGE ON INK JET RECORDING APPARATUS
SEND ELEMENT CHARACTERISTIC DETECTION SIGNAL TO ACTUATOR
S0
(A)
IS ELEMENT CHARACTERISTIC VALUE OF ACTUATOR WITHIN PREDETERMINED RANGE?
NO
ERROR 0
YES
SEND OPERATION SIGNAL TO ACTUATOR
S1
(B)
DID ACTUATOR PERFORM PREDETERMINED OPERATION ?
NO
ERROR 1
YES
S3
ERROR DISPLAY
INK CARTRIDGE EXCHANGE
(C)
IS INITIAL OSCILLATION CHARACTERISTIC VALUE DETECTED BY ACTUATOR WITHIN PREDETERMINED RANGE?
NO
ERROR 2
YES
RETURN
S2
SELECTION BY USER

Fig. 9

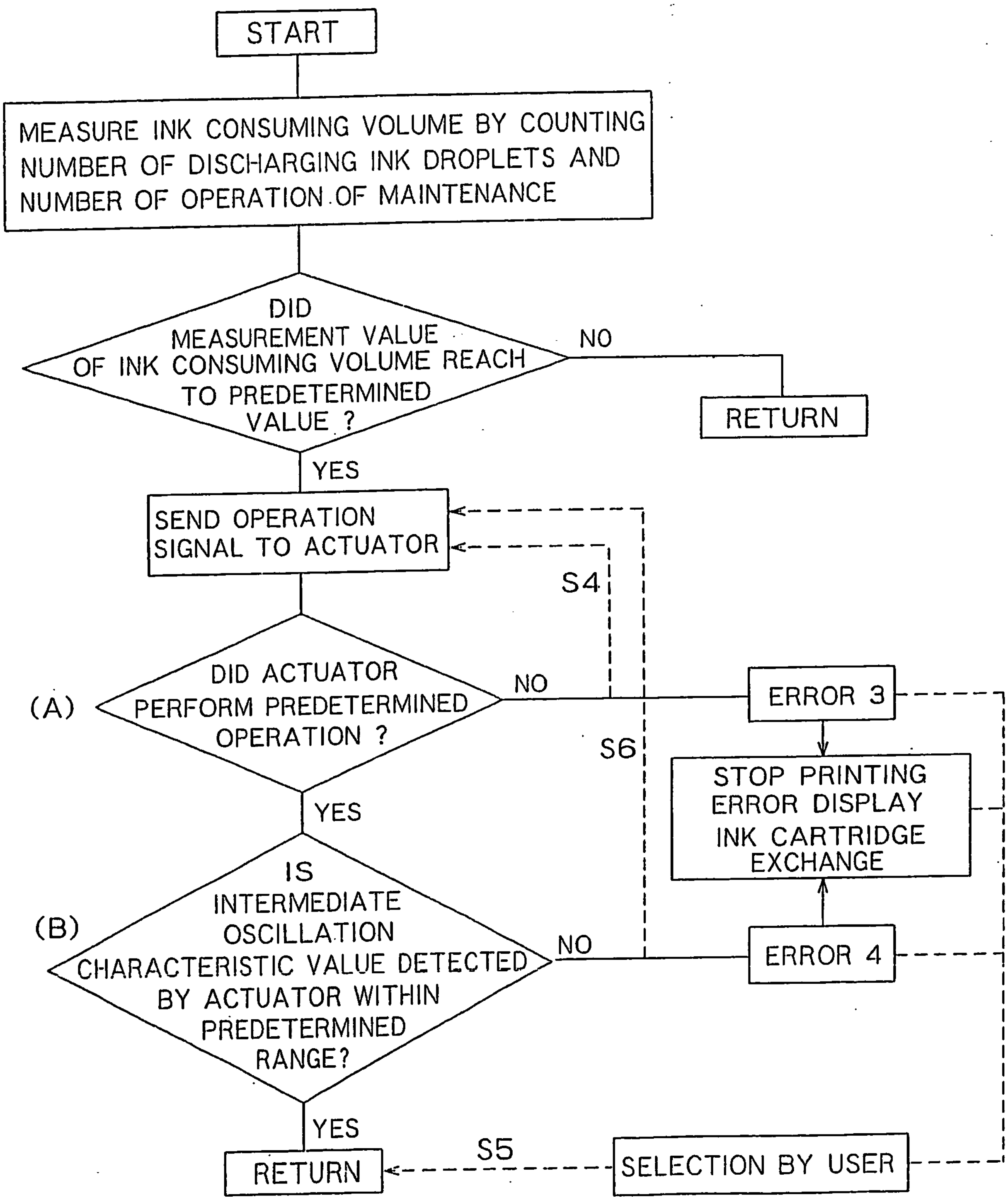

START
MEASURE INK CONSUMING VOLUME BY COUNTING NUMBER OF DISCHARGING INK DROPLETS AND NUMBER OF OPERATION OF MAINTENANCE
DID MEASUREMENT VALUE OF INK CONSUMING VOLUME REACH TO PREDETERMINED VALUE ?
NO
RETURN
YES
SEND OPERATION SIGNAL TO ACTUATOR
S4
(A)
DID ACTUATOR PERFORM PREDETERMINED OPERATION ?
NO
ERROR 3
S6
STOP PRINTING ERROR DISPLAY INK CARTRIDGE EXCHANGE
YES
(B)
IS INTERMEDIATE OSCILLATION CHARACTERISTIC VALUE DETECTED BY ACTUATOR WITHIN PREDETERMINED RANGE?
NO
ERROR 4
YES
RETURN
S5
SELECTION BY USER

Fig. 10

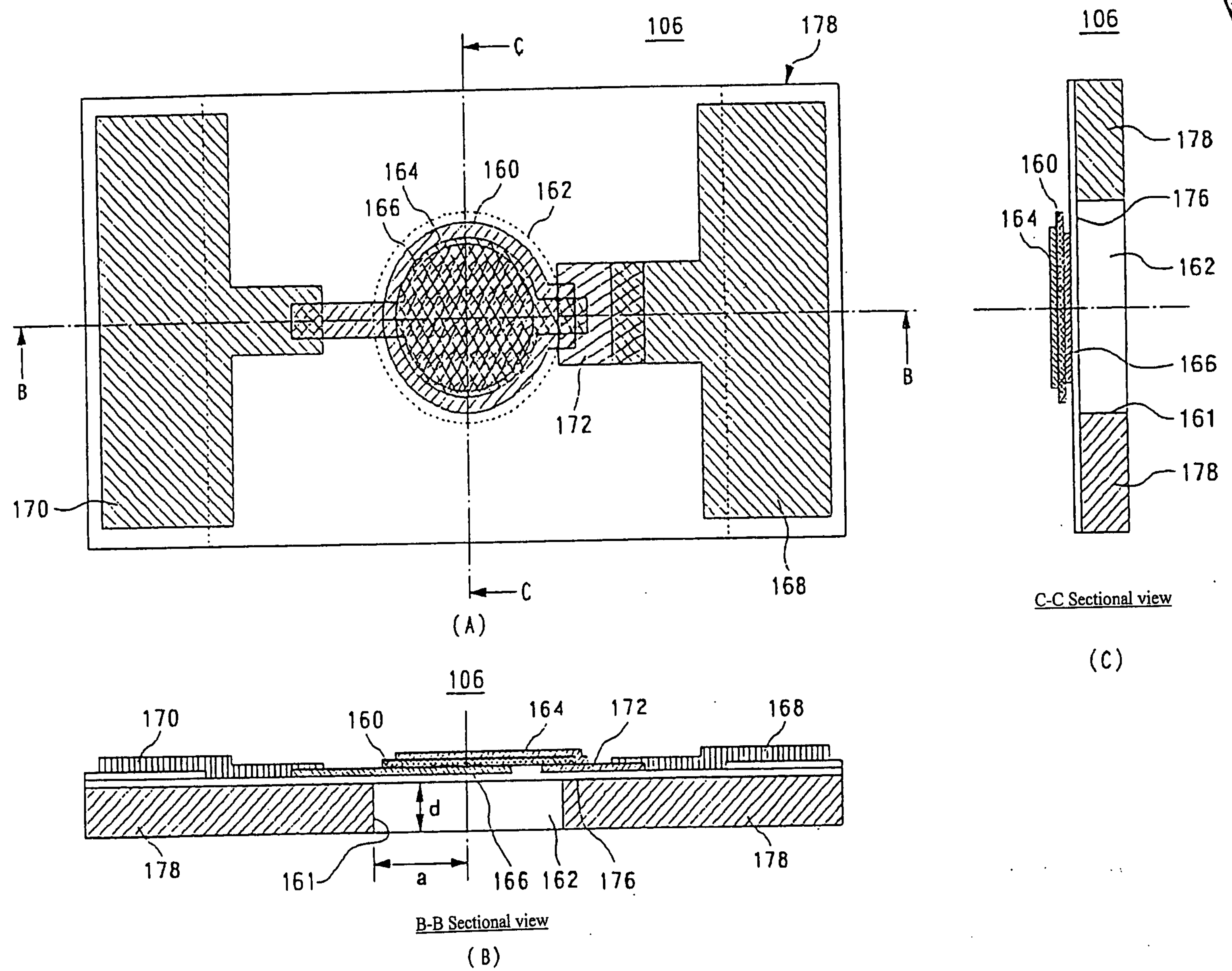

106
178
C
C
164
160
162
166
B
B
172
170
168
(A)
106
178
160
176
164
162
166
161
178
C-C Sectional view
(C)
106
170
160
164
172
168
d
178
161
a
166
162
176
178
B-B Sectional view
(B)

Fig. 11

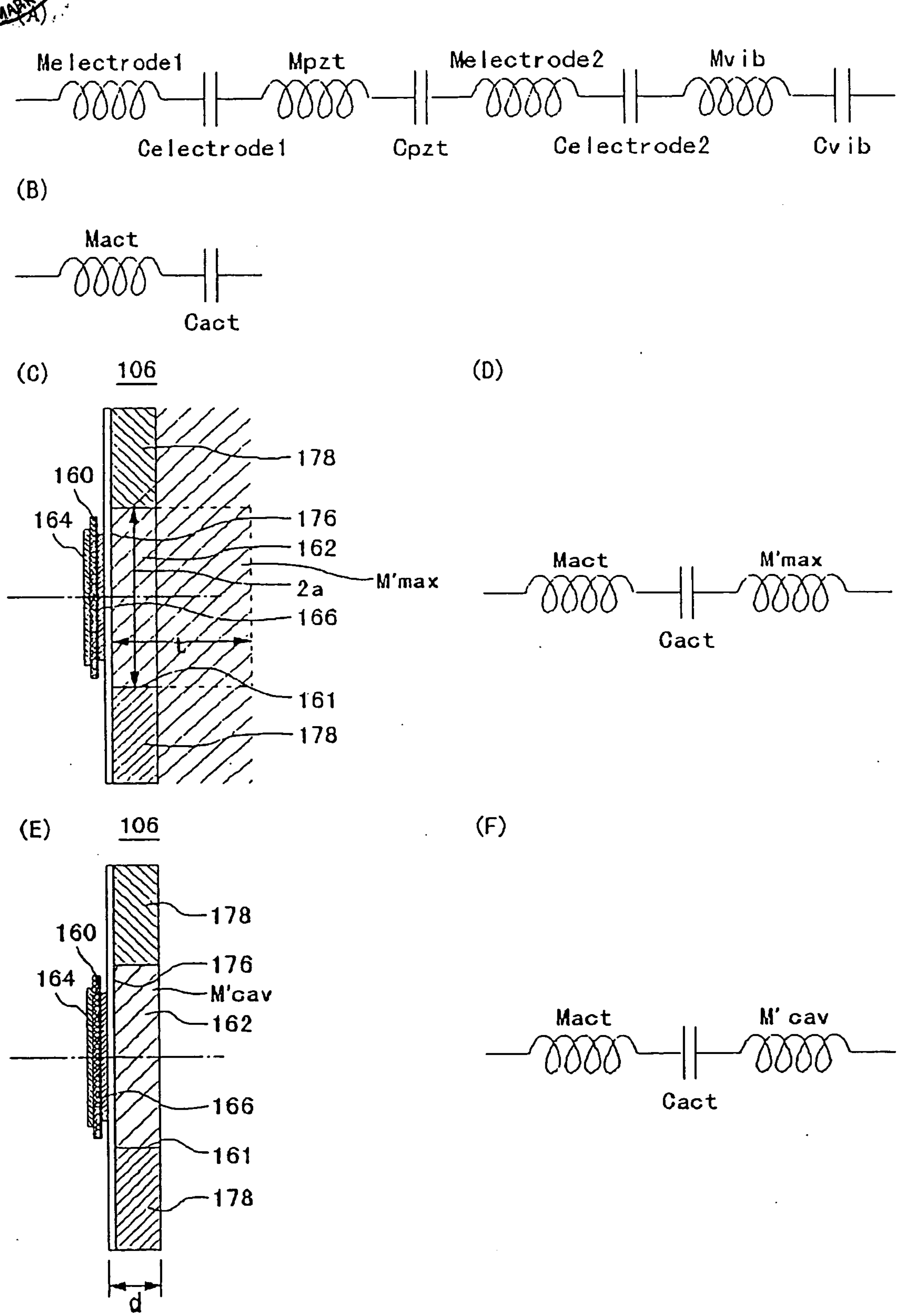
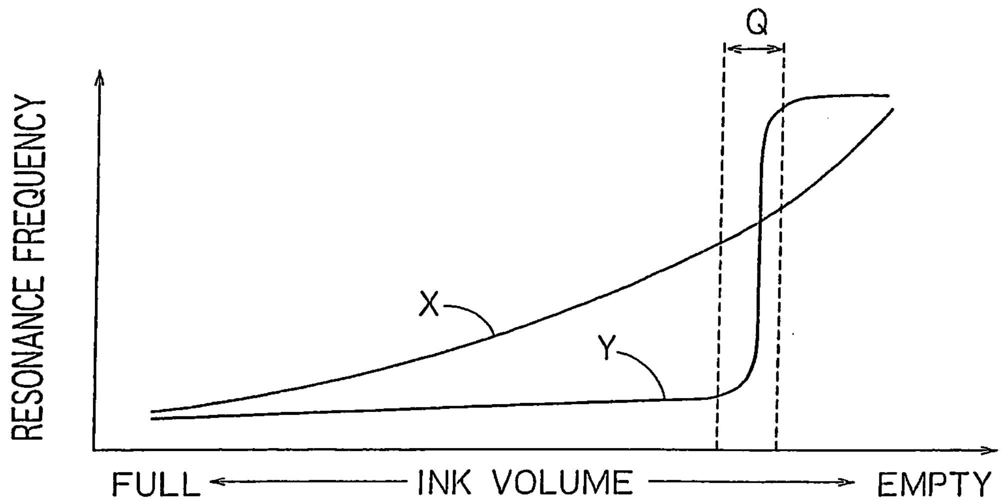
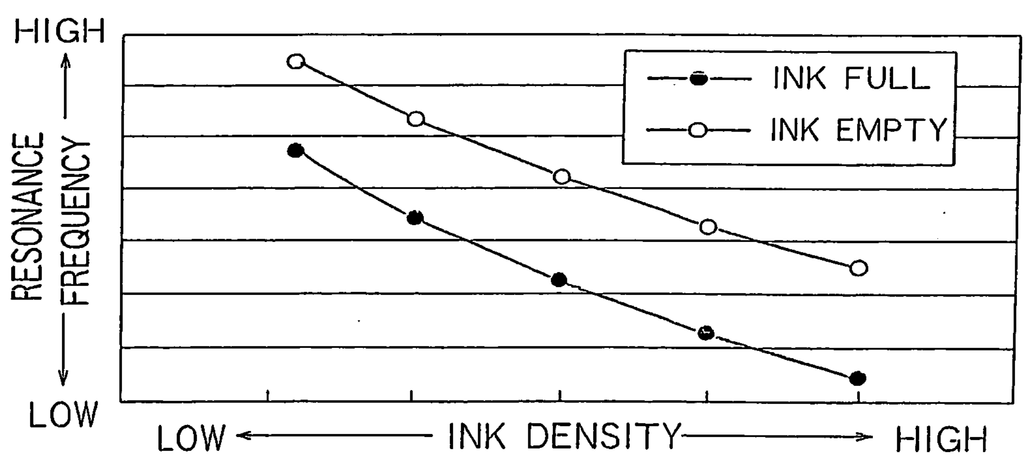

(A)
Melectrode1
Mpzt
Melectrode2
Mvib
Celectrode1
Cpzt
Celectrode2
Cvib
(B)
Mact
Cact
(C)
106
178
160
164
176
162
M'max
2a
166
t
161
178
(D)
Mact
M'max
Cact
(E)
106
178
160
164
176
M'cav
162
166
161
178
d
(F)
Mact
M' cav
Cact

Fig. 12

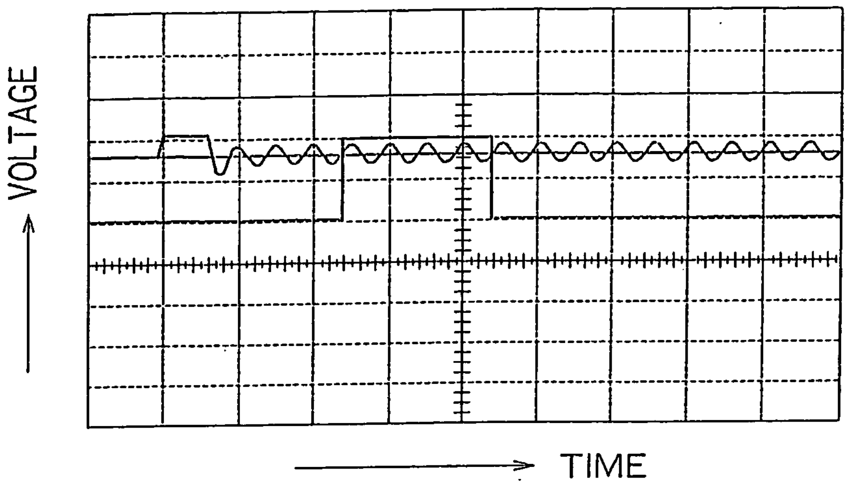

Q
RESONANCE FREQUENCY
X
Y
FULL
INK VOLUME
EMPTY

(A)

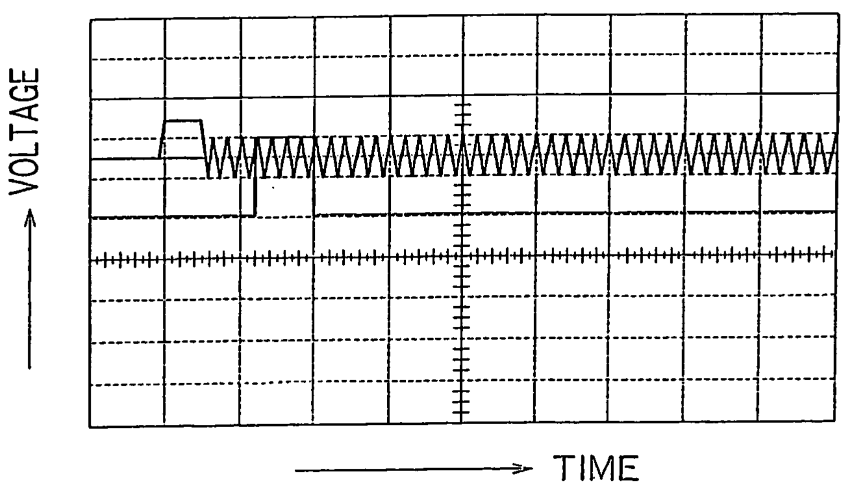

HIGH
RESONANCE FREQUENCY
LOW
INK FULL
INK EMPTY
LOW
INK DENSITY
HIGH

(B)

Fig. 13



(A)



(B)

Fig. 14

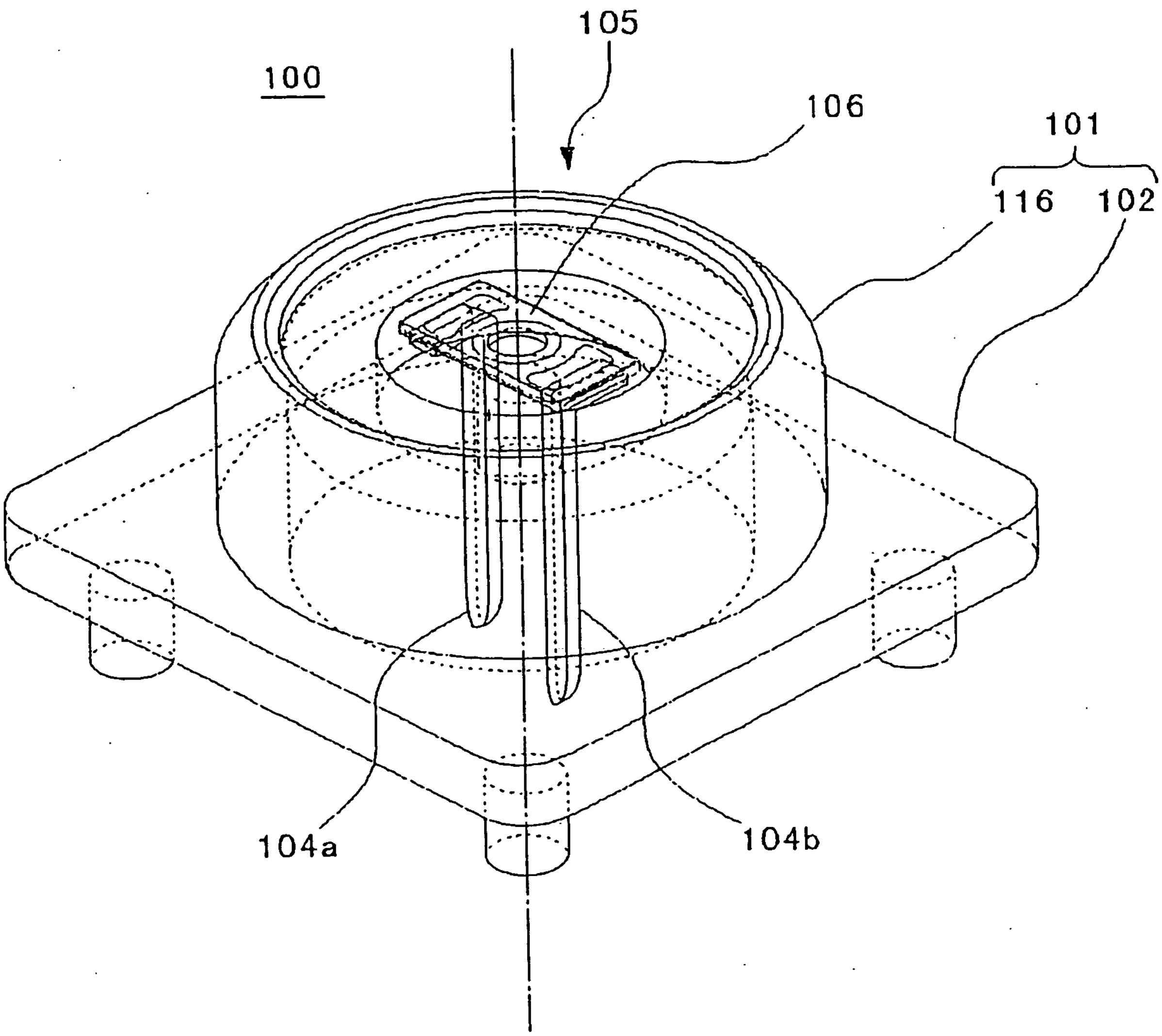


Fig. 15

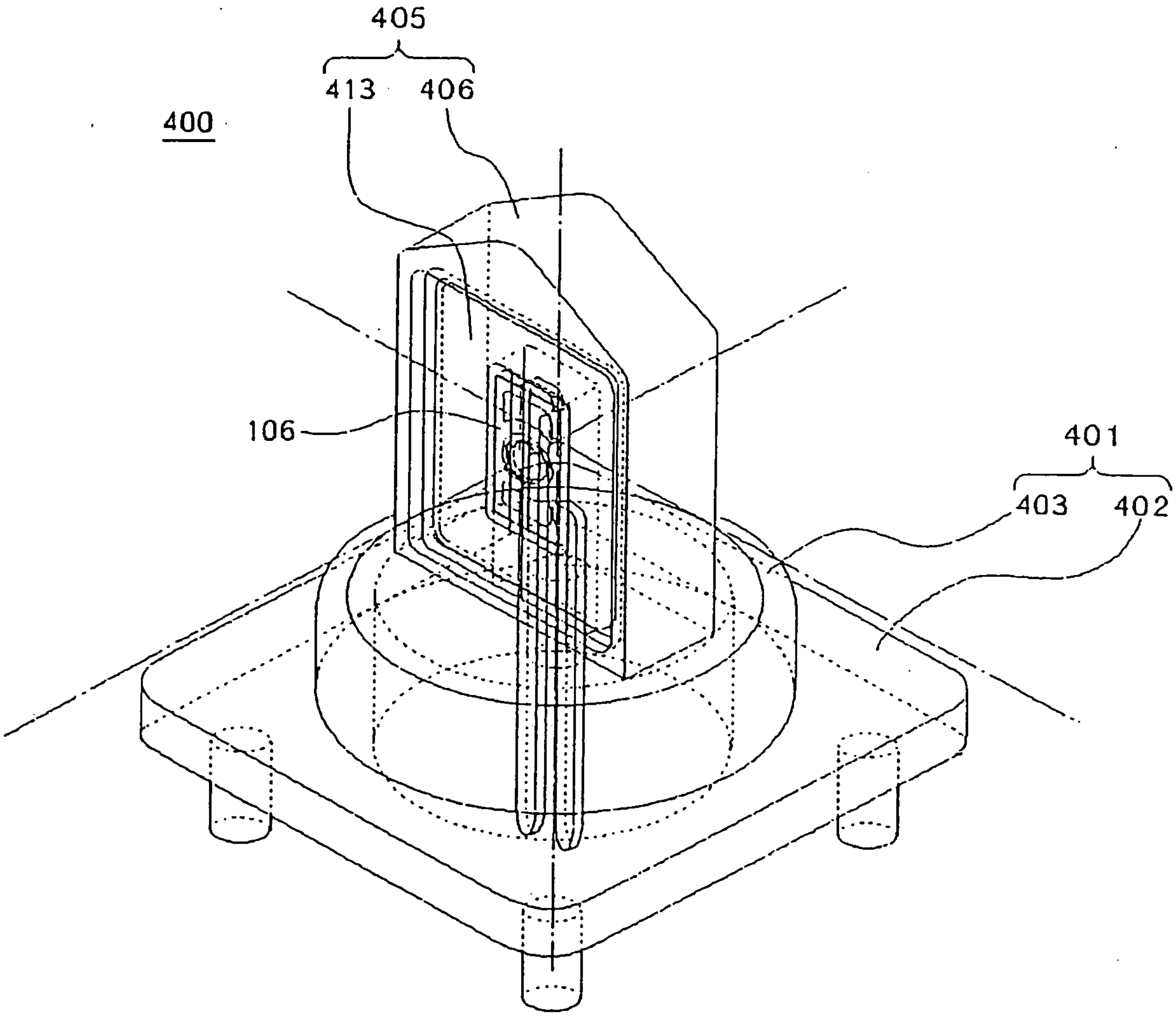


Fig. 16

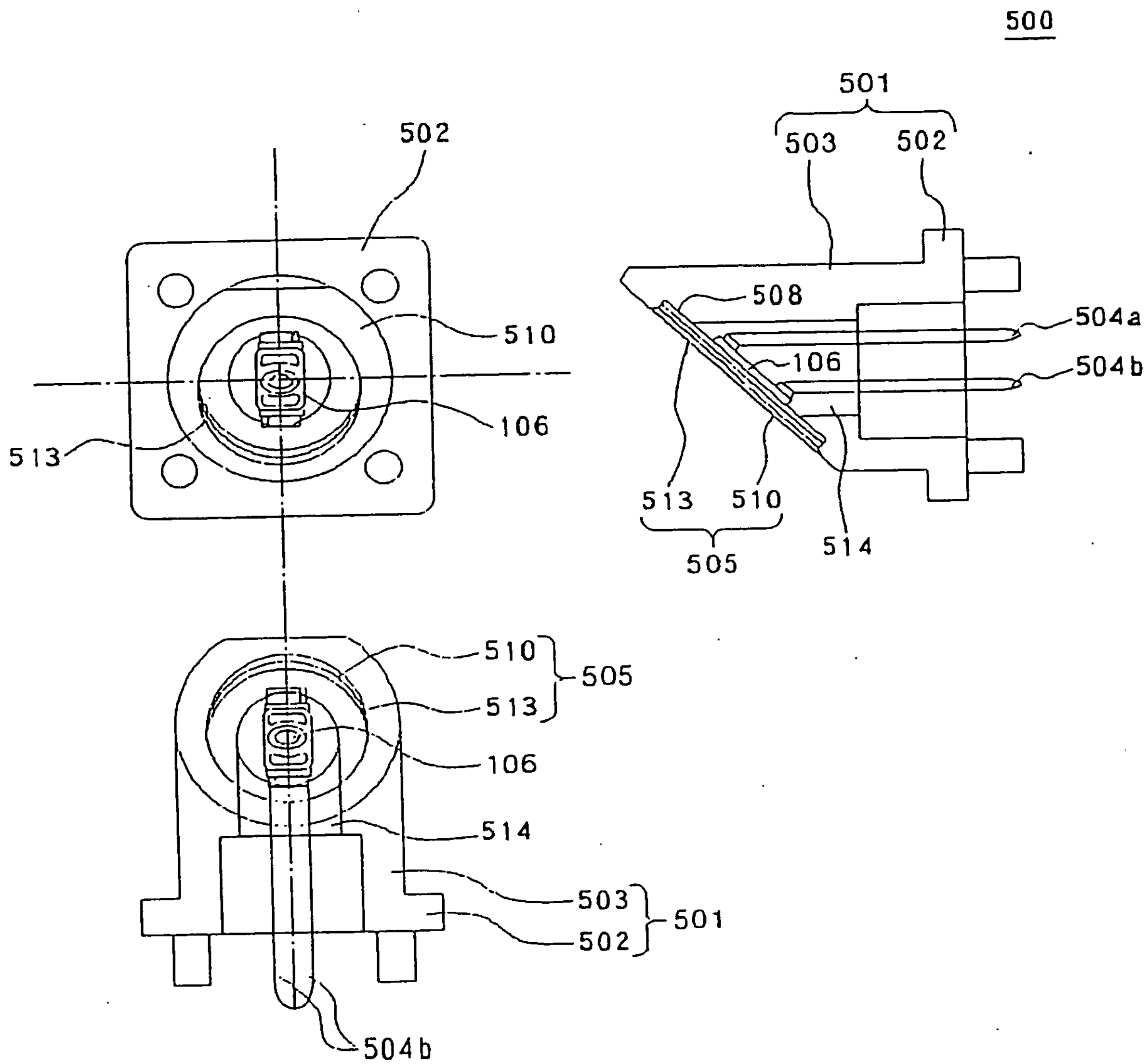

500
501
503
502
508
504a
106
504b
513
510
505
514
502
510
106
513
510
505
513
106
514
503
501
502
504b

Fig. 17

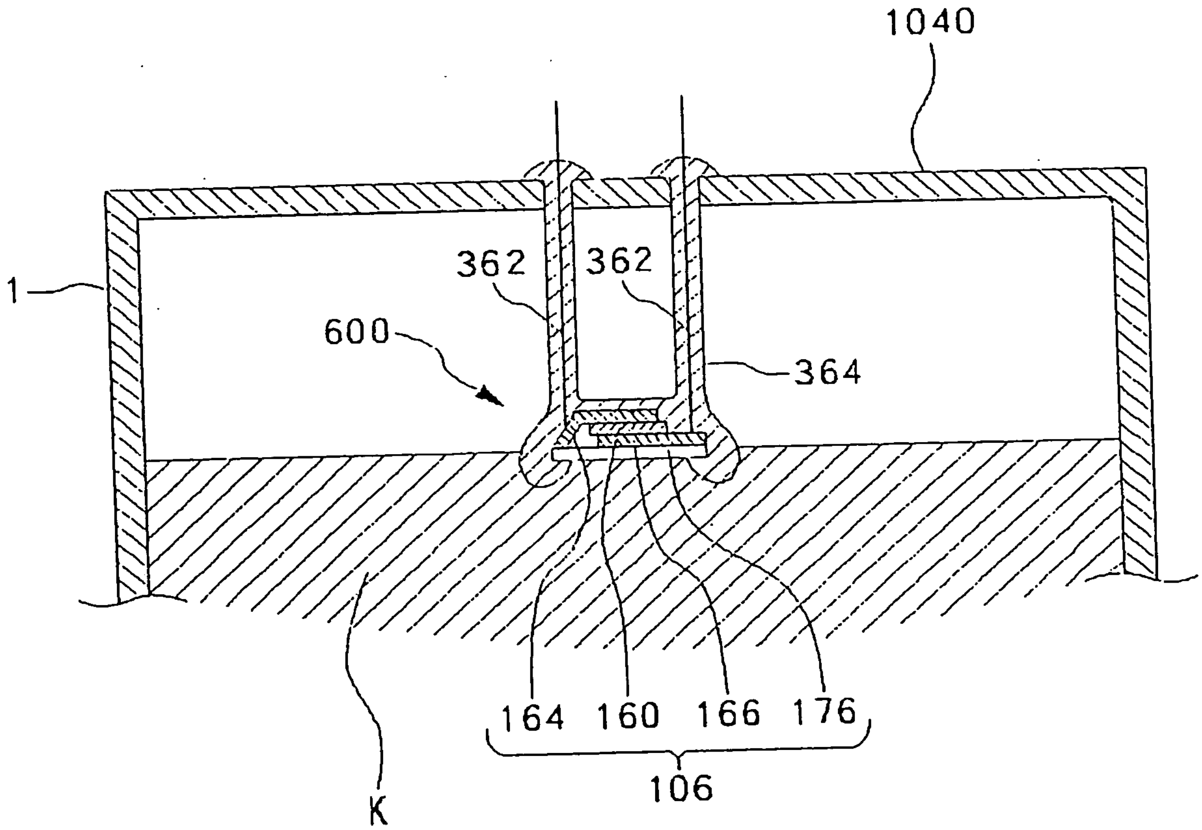


Fig. 18

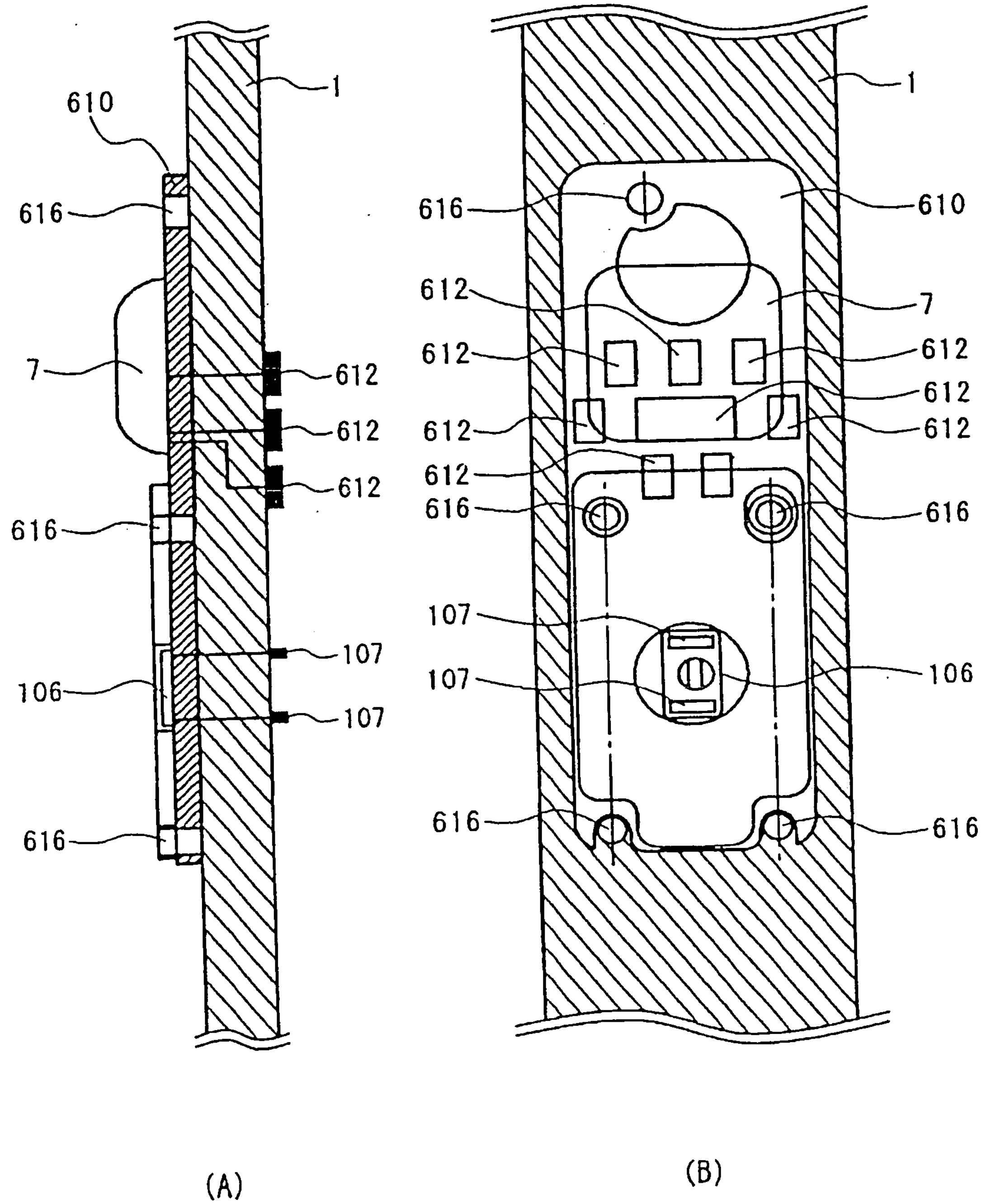

610
616
7
612
612
612
616
106
107
107
616
1
(A)
616
610
612
7
612
612
612
612
612
612
616
616
107
106
107
616
616
1
(B)

Fig. 19

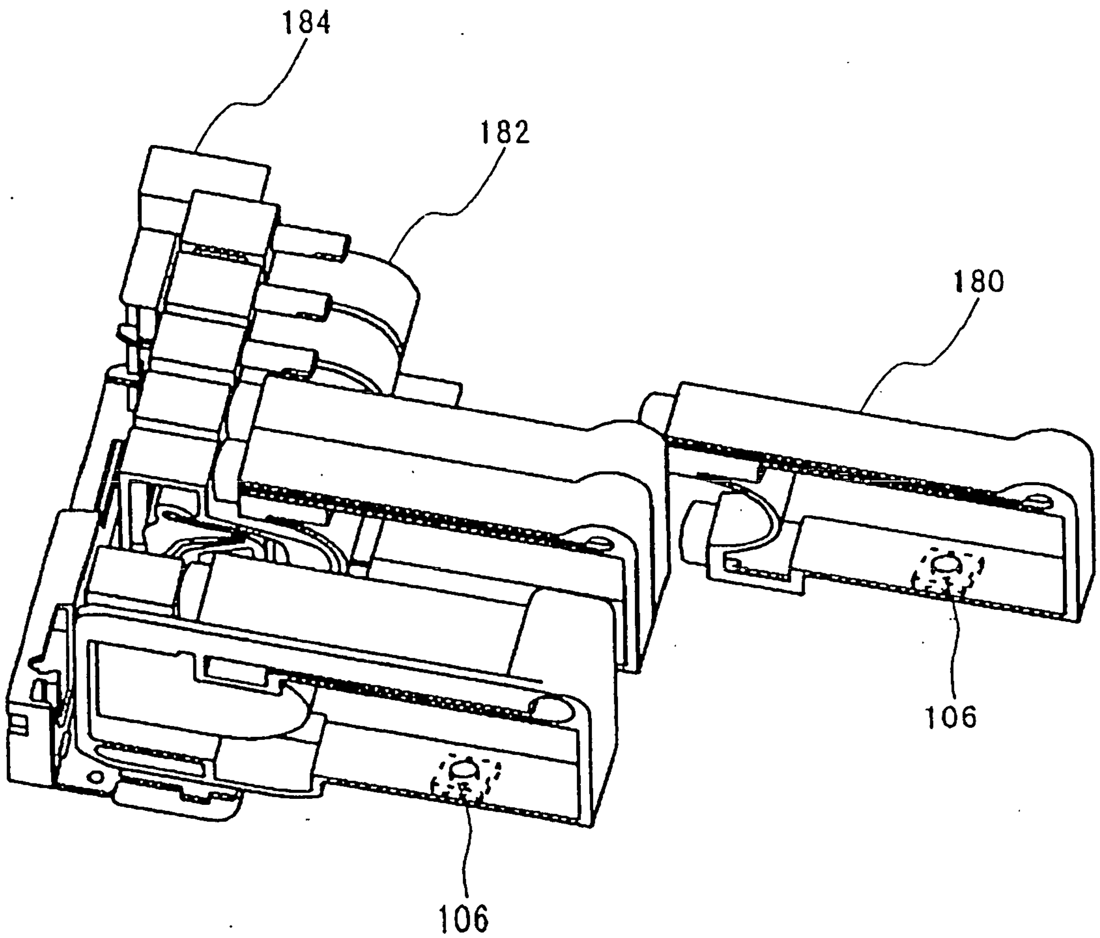


Fig. 20

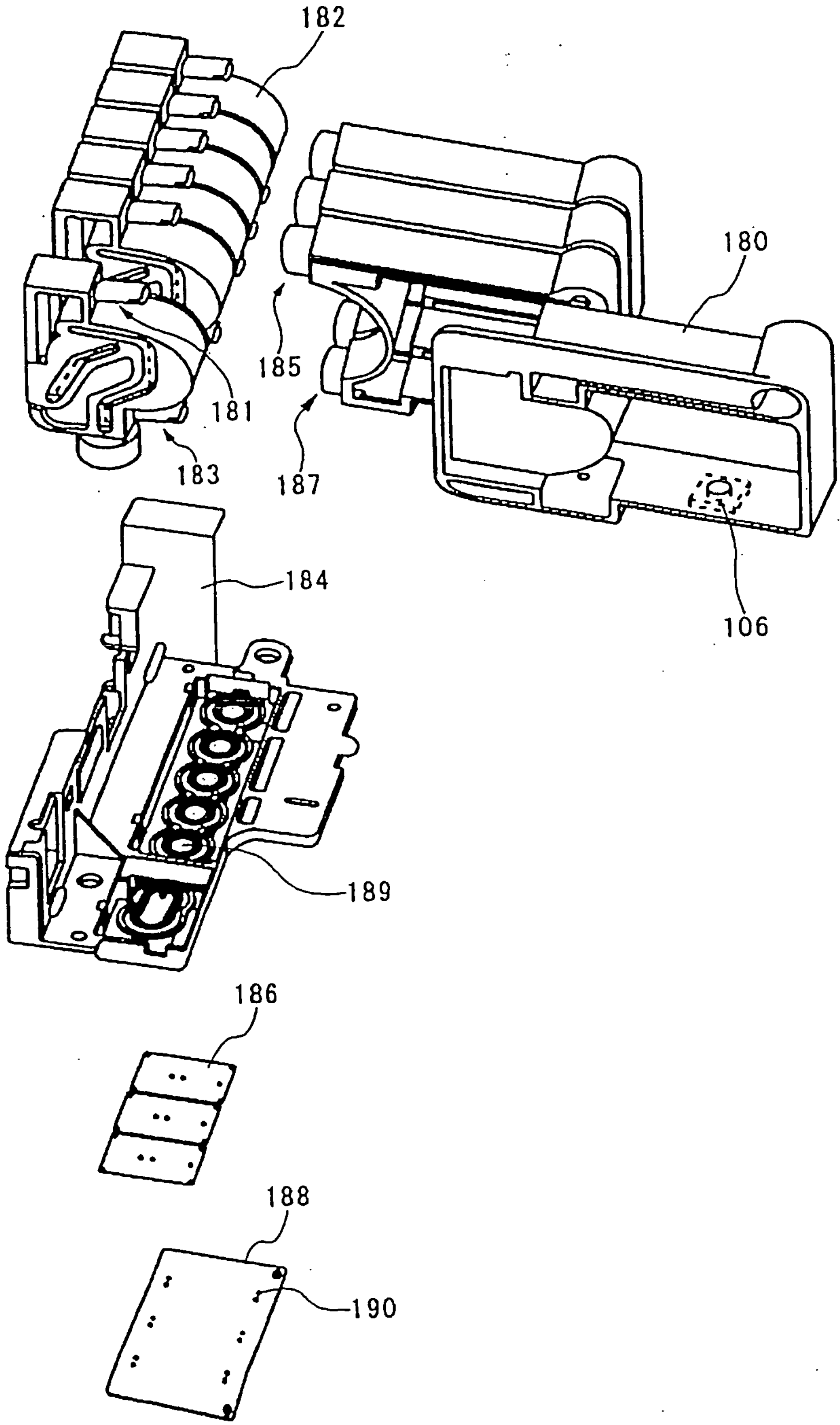


Fig. 21

ABSTRACT

[Summary]

[Object]

The invention provides a liquid container, an ink jet recording apparatus, and a method of judging the working of an ink jet recording apparatus based on detection results of an ink volume. It is possible to judge whether or not the piezoelectric device is normally operated, to confirm the liquid of the predetermined volume is contained in the liquid container, to detect deficiencies of the liquid container and the piezoelectric device, and to detect a gradient of the liquid container when the liquid container is not properly mounted.

[Methods of Solving the Problems]

The liquid container of the present invention is equipped with a container for containing a liquid, a liquid supply opening for supplying the liquid to the external of the container, and a piezoelectric device for detecting a consumption state of the liquid on the internal wall in the container. The oscillation region of the piezoelectric device is located at the slightly upper or lower position with respect to the liquid level of the liquid when the liquid is not consumed. A characteristic value of the piezoelectric device is detected in the detection section, and the judgment section judges whether or not the predetermined condition is satisfied or not. The ink jet recording apparatus is in an operable state or a non-operable state based on the judgment results.

[Selected Figure]

Fig. 7.